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ANALYSIS AND EVALUATION OF FORECASTING METHODS AND TOOLS TO PREDICT FUTURE DEMAND FOR SECONDARY CHEMICAL-BIOLOGICAL CONFIGURATION ITEMS

by

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June 2013

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As the Engineering Support Activity (ESA) for numerous consumable Chemical Biological items managed by the Defense Logistics Agency (DLA), Edgewood Chemical Biological Center (ECBC) must be able to complete reviews of all procurement packages within 15 calendar days. With such little lead time, it would be very beneficial if ECBC had the ability to forecast when DLA procurement actions will occur. This thesis presents an evaluation of the effectiveness of Simple Regression and Exponentially Weighted Moving Average (EWMA) forecasting models to predict the demand of Chemical Biological consumable items using the procurement history data for four specific items. Neither forecasting model proved effective at predicting the demand for the items due in large part to large variation in demand patterns. The inventory policies and supply issues which currently exist at an Army production site were investigated and it was recommended to consider Economic Order Quantity (EOQ) or Just-in-Time (JIT) inventory management models as possible alternatives to achieve smoother demand patterns. Additionally, recommendations were made to examine the integrity of the historical demand data as well as using a Multiple Regression forecast model with several causal effects in addition to time.

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ANALYSIS AND EVALUATION OF FORECASTING METHODS AND TOOLS TO PREDICT FUTURE DEMAND FOR SECONDARY CHEMICAL-BIOLOGICAL CONFIGURATION ITEMS

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ABSTRACT

As the Engineering Support Activity (ESA) for numerous consumable Chemical Biological items managed by the Defense Logistics Agency (DLA), Edgewood Chemical Biological Center (ECBC) must be able to complete reviews of all procurement packages within 15 calendar days. With such little lead time, it would be very beneficial if ECBC had the ability to forecast when DLA procurement actions will occur. This thesis presents an evaluation of the effectiveness of Simple Regression and Exponentially Weighted Moving Average (EWMA) forecasting models to predict the demand of Chemical Biological consumable items using the procurement history data for four specific items. Neither forecasting model proved effective at predicting the demand for the items due in large part to large variation in demand patterns. The inventory policies and supply issues which currently exist at an Army production site were investigated and it was recommended to consider Economic Order Quantity (EOQ) or Just-in-Time (JIT) inventory management models as possible alternatives to achieve smoother demand patterns. Additionally, recommendations were made to examine the integrity of the historical demand data as well as using a Multiple Regression forecast model with several causal effects in addition to time.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAC	Acquisition Advice Code
AESIP	Army Enterprise Systems Integration Program
AMC	Army Materiel Command
BRAC	Base Realignment and Closure
CB	Chemical and Biological
CBERT	Chemical Biological Equipment Repair Team
CBO	Congressional Budget Office
CIT	Consumable Item Transfer
CUSUM	Cumulative Sum
DI	Due In
DLA	Defense Logistics Agency
DLIS	Defense Logistics Information Service
DLR	Depot Level Reparable
DO	Due Out
DoD	Department of Defense
ECBC	Edgewood Chemical Biological Center
EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
ESA	Engineering Support Activity
EWMA	Exponentially Weighted Moving Average
FLIS	Federal Logistics Information System
FY	Fiscal Year
GAO	Government Accountability Office
GCSS	Global Combat Support System
GFM	Government Furnished Material
GPFU	Gas-Particulate Filter Unit
IDIQ	Indefinite Delivery/Indefinite Quantity

IMM	Integrated Materiel Manager
IPT	Integrated Product Team
JIT	Just-in-Time
JSGPM	Joint Services General Purpose Mask
LCMC	Life Cycle Management Command
LIW	Logistics Information Warehouse
LMP	Logistics Modernization Program
MAD	Mean Absolute Deviation
MAPE	Mean Absolute Percentage Error
MOA	Memorandum of Agreement
MRP	Material Requirements Planning
MSD	Mean Squared Deviation
MSE	Mean Square Error
NSN	National Stock Number
OEM	Original Equipment Manufacturer
OH	On Hand
OSTL	Order Ship Time Level
PDM	Product Data Management
PE	Protective Entrance
PPI	Procurement Package Input
RBOM	Repair Bill of Materials
RDEC	Research, Development and Engineering Center
RO	Requisitioning Objective
ROP	Reorder Point
SAP	Security Assistance Program
SL	Safety Level
SPR	Special Program Request
TACOM	U.S. Army Tank-automotive and Armaments Command
TDP	Technical Data Package

EXECUTIVE SUMMARY

Edgewood Chemical Biological Center (ECBC) serves as the Engineering Support Activity (ESA) for numerous Chemical-Biological items, providing advice on market research and company capabilities, testing and inspection, and other technical areas as well as assuring the Technical Data Packages (TDPs) are accurate and all documentation current. As of 2010, item management responsibilities for most consumable items supported by ECBC have been transitioned from U.S. Army Tank -automotive and Armaments Command (TACOM) to the Defense Logistics Agency (DLA). Whereas TACOM provided built-in administrative lead time for the acquisition IPTs to review the procurement packages, including the TDPs, DLA does not. DLA comes to ECBC each time they need to procure parts for which ECBC is the ESA with a requirement of a very quick turnaround for these procurement actions (often within 15 calendar days). Often, ECBC finds it very difficult to meet this quick turnaround and it would be very beneficial if ECBC had the ability to forecast when DLA procurement actions will occur. Additionally, DLA would benefit from the ability to forecast future procurements as well, as this would help them to further mitigate any shortages of critical parts.

In order to analyze various forecasting methods, this thesis focused on the inventory data for the chemical-biological consumable items procured by DLA for which ECBC is the ESA, using input from various sources including DOD EMALL, the Federal Logistics Information System (FLIS), the Army's Logistics Information Warehouse (LIW), and TACOM item managers who managed these parts prior to transition to DLA.

The U.S. Army prescribes guidance and procedural instructions for computing requirements for its secondary items inventory. Army Item Managers are responsible for developing inventory management plans for their assigned items, including the coordination of all purchase and repair decisions. In order to determine the appropriate inventory levels, the Army uses a cost differential model which is based on several variables including procurement costs, holding costs, frequency of demand, implied stockage cost, and the probability of future demand (GAO, 2009). Army's Logistics

Modernization Program (LMP) tracks and monitors supply at each Army Depot and automatically submits a requisition to DLA when the reorder point is reached. LMP is also used by production sites, i.e., Pine Bluff Arsenal, to submit requisitions to DLA for parts when a requirement exists.

DLA manages almost every consumable item the Military Services need to operate through three supply centers and 26 distribution centers (Depots). DLA Demand Planners use historical demand combined with known future requirements from Army Depot Special Program Requirements and other correspondence to forecast demand.

DOD EMALL provides tracking capabilities for all DLA requisitions and orders as well as visibility of all current assets. Once a requisition is received by DLA, it is determined whether the on-hand quantity will meet the requirement. If there is sufficient inventory on hand, an order is placed by DLA to the distribution center(s) and the items are delivered to the customer. If there is not sufficient inventory on hand, a procurement action is initiated by DLA and an order placed with a manufacturer or vendor to deliver the items to the customer.

The effectiveness of Simple Regression and EWMA forecasting models to predict the demand of Chemical Biological consumable items, using the procurement history data for four specific items was evaluated. The software Minitab was chosen to perform the statistical analysis since it is used widely in industry and the military. The four data sets were determined by selecting consumable items managed by ECBC for which DLA has requested a Technical Data Package at least one time during the past three years using specific selection criteria including past demand volume, item unit cost, percent of back orders, and lumpiness of past demand patterns.

In this thesis, it is demonstrated that neither Simple Regression nor EWMA forecasting models are effective at predicting the demand of Chemical Biological consumable items using historical demand data due in large part to large variation in demand patterns—the demand is not in a state of statistical control. A primary reason for this large variation is an apparent lack of both trust and communication between DLA and

US Army Arsenals. Though the production quantities are level at Pine Bluff Arsenal, they continue to order large quantities at varying time intervals due to an apparent lack of confidence that DLA will deliver the required stock when required. The inventory policies and supply issues which currently exist at Pine Bluff Arsenal were investigated and it was recommended to consider economic order quantity (EOQ) or Just-in-Time (JIT) inventory management models as possible alternatives to achieve smoother demand patterns.

The EOQ model is the simplest and most fundamental of all inventory models and describes the important trade-off between ordering and holding costs. The objective is to choose the order quantity Q to minimize the average cost per unit time.

JIT is a production strategy developed within the Japanese auto as a way to reduce inventory and associated storage costs, to reduce waste, and to raise the quality of the products. JIT requires better relationships with suppliers and those suppliers must be willing to absorb some uncertainty and adjust delivery quantities and timing of the deliveries to match production rates.

Additionally, recommendations were made to examine the integrity of the historical demand data as well as using a Multiple Regression forecast model with several causal effects in addition to time.

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I. INTRODUCTION

A. BACKGROUND

Systems Engineering is concerned with the entire life-cycle of a system, including support of the fielded system. This thesis examines supportability issues related to repair parts availability and related logistics policy for a class of protective systems important to the US Army.

The U.S. Army Edgewood Chemical Biological Center (ECBC) is the nation's principal research and development resource for non-medical chemical and biological (CB) defense. As a critical national asset in the CB defense community, ECBC supports all phases of the acquisition life-cycle—from basic and applied research through technology development, engineering design, equipment evaluation, product support, sustainment, field operations and demilitarization—to address its customers' unique requirements (ECBC, n.d.).

The U.S. Army Tank-automotive and Armaments Command (TACOM) Life Cycle Management Command (LCMC), headquartered in Warren, Michigan, in partnership with the Army's Program Executive Offices, is one of the Army's largest weapon systems research, development, and sustainment organizations. TACOM is responsible for insuring war fighting readiness for the soldier by purchasing ground combat, combat support and combat service support items for the military as well as sustaining the current systems through lifecycle maintenance (U.S. Army TACOM LCMC, n.d.).

The Defense Logistics Agency (DLA), headquartered in Fort Belvoir, Virginia, provides the Army, Navy, Air Force, Marine Corps, other federal agencies, and combined and allied forces with the full spectrum of logistics, acquisition and technical services. DLA serves as the item manager for nearly 100 percent of the military forces' consumable items required to operate, including food, fuel, energy, uniforms, medical supplies, and construction and barrier equipment. DLA also supplies more than 84 percent of the military's spare parts. Additionally, DLA manages the reutilization of

military equipment, provides catalogs and other logistics information products, and offers document automation and production services (DLA, n.d.).

In 2002, the Army established an equipment "reset" program, simply termed "Reset," to reverse the effects of combat stress on equipment used in Iraq and Afghanistan. Due to the higher operating tempo, rough desert environments, and limited field-level maintenance in theater, combat equipment is aging four times faster than originally envisioned. In order to maintain operational readiness, units must ensure that their equipment is returned to optimal condition, or "reset" after redeploying. There are three components of the Reset program: Repair, Recapitalization, and Replacement. Repair may be done as part of field or depot level maintenance, to correct equipment faults. Recapitalization is the restoration of equipment's useful life and the removal of damage and stress incurred during deployment, and in some instances may include technology insertion to enhance equipment configurations, resulting in improved warfighter survivability and better equipment performance. Replacement involves the procurement of new items/parts to replace battle losses as well as items deemed irreparable upon their return (referred to as "washouts"). Equipment Reset is required for all redeployments and involves full engagement by everyone in the supply chain – DLA, depots, arsenals, original equipment manufacturers (OEMs), and suppliers. Since its conception, the Army Reset program has enabled the Army to maintain operational readiness of ground combat equipment at over 90 percent (Coryell & Lenaers, 2006; CBO, 2007).

Between August 2009 and December 2010, item management responsibilities for most consumable items supported by Edgewood Chemical Biological Center (ECBC) were transitioned from the TACOM to the DLA as part of the Consumable Item Transfer (CIT) initiative. An agreement was signed between Army Materiel Command and DLA to make sure DLA comes to Army each time they need to procure parts, but DLA has a requirement of a very quick turnaround for these procurement actions (often within 15 calendar days). Currently, much of the demand for the consumable items supported by ECBC is in support of the Army Reset Program. Most of the Army's equipment in theater moves in and out with the units to which it is assigned. Since Army units are typically

rotated in and out of theater roughly annually, the size of the Army's force in Iraq and Afghanistan should be the main determinant of the number of pieces of equipment the Army expects will be Reset each year. Additionally, the proportion of the Army's equipment currently in Iraq and Afghanistan corresponds roughly to the share of its forces deployed there. The Army's goal is to Reset each redeployed unit's equipment within 180 days of its return to home station (Coryell & Lenaers, 2006; CBO, 2007).

In order to reduce acquisition lead time, it would be very helpful if the Engineering Support Activities (ESAs) had the ability to forecast when DLA procurement actions will occur. Additionally, DLA would benefit from the ability to forecast future procurements as well, as this would help them to further mitigate any shortages of critical parts. This thesis identifies forecasting methods which may be used for procurement of spare/repair parts for which ECBC provides engineering support and provides an analysis of these methods to determine which may provide the best results.

B. PURPOSE OF STUDY

This research recommends a best forecasting method and/or set of tools for predicting future demand for chemical biological secondary configuration items in order to optimize inventories as well as reduce lead times between procurement requests and delivery of certified Technical Data Packages.

C. RESEARCH QUESTIONS

1. How accurately can we forecast future procurement actions for chemical-biological spares using data from DOD EMALL, the IHS Haystack Gold, and the Army's Logistics Information Warehouse (LIW)?
2. How accurately can we forecast using our own data from past procurement actions?
3. What method(s) produce(s) the best results?

D. BENEFITS OF STUDY

This thesis provides a forecasting solution for the Edgewood Chemical Biological Center which will optimize chemical biological secondary item part inventories as well as reduce lead times between procurement requests and delivery of certified Technical Data

Packages. This will help assure parts are available to the soldier when needed while also providing cost savings incurred by excessive part inventories. This forecasting solution will also benefit the item managers for these parts at the Tank Automotive Command (TACOM) and the Defense Logistics Agency (DLA).

E. SCOPE AND METHODOLOGY

This thesis focuses on the inventory data for the chemical-biological consumable items procured by DLA for which engineering support is performed by ECBC. Input will be from various sources including DOD EMALL, the Federal Logistics Information System (FLIS), the Army's Logistics Information Warehouse (LIW), and TACOM item managers who managed these parts prior to transition to DLA. Most of the analysis will be dependent on these data and inputs.

The methodology includes a literary review of forecasting techniques as well as a study of historical methods used for forecasting procurements of chemical-biological spare/repair parts. Past and present inventory data as well as historical procurement data will be gathered and used to analyze various forecasting methods to determine which methods provide the most accurate results and develop recommendations for improving Army and/or DLA forecasting of the demand. Chemical-biological spare/repair parts which significantly affect operational readiness will be used for the analysis.

II. CHEMICAL-BIOLOGICAL SPARE PARTS PROCUREMENT OVERVIEW

A. INTRODUCTION

This section provides a general overview of the ECBC Procurement Package Input (PPI) Process and the requirement for Technical Data Package review and certification as outlined in the Memorandum of Agreement (MOA) signed between the DLA and ECBC, and DLA's supply chain management process.

B. ECBC PROCUREMENT PACKAGE INPUT PROCESS

ECBC serves as the Engineering Support Activity (ESA) for numerous Chemical-Biological items, which, historically were all managed by TACOM. TACOM's approach for procurement typically uses an Integrated Product Team (IPT) for the acquisition of an item. ECBC personnel serve as members of the IPT, providing advice on market research and company capabilities, testing and inspection, and other technical areas as well as assuring the Technical Data Packages (TDPs) are accurate and all documentation is up to date (ECBC, 2010). Historically, TACOM has utilized various forecasting strategies to ensure an acceptable level of supply and provided built-in lead time for the acquisition IPTs to review the procurement packages, including the TDPs. Between August 2009 and December 2010, item management responsibilities for most consumable items supported by ECBC were transitioned from TACOM to the Defense Logistics Agency (DLA).

DLA does not use the same IPT approach for acquisition as that used by TACOM, but rather automated processes which use item coding to trigger their procurement actions (ECBC, 2010). To mitigate shortages of critical parts, DLA has shortened or eliminated their acquisition lead times, often resulting in the ordering spare/repair parts without getting the correct (up to date and certified) Product Data. An agreement was signed between Army Materiel Command (AMC) and DLA to make sure DLA comes to Army each time they need to procure parts, but Army has a requirement of a very quick turnaround for these procurement actions (often within 15 calendar days). Research, Development and Engineering Centers (RDECs) providing Configuration

Management for these CIs must assure the technical data required to procure the parts is certified for use when a new procurement action is initiated by the Item Manager. DLA does not forecast demand of their items well, and in most cases they only place orders for their customers when there is a requirement.

C. SUPPLY CHAIN MANAGEMENT PROCESS FOR DLA MANAGED ITEMS

As part of the 2005 Base Realignment and Closure (BRAC), the item management of Depot Level Reparables (DLRs) and most consumable items was transferred from the Military Services to the DLA, providing a single, integrated procurement management provider to support all Military Service requirements. The primary goal is to save DOD money by leveraging all procurement buys and managing them within a single agency.

The DOD Supply Chain Materiel Management Regulation (DoDD 4140.1-R) requires the Military Services to aggressively pursue the lowest possible acquisition lead times, which in turn reduces the amount of inventory each site maintains on-hand to cover supply and demand fluctuations (known as the “safety” level). Acquisition lead time measures the length of time between the initiation of a procurement action and the receipt of items into the supply system. The regulation also encourages the use of Economic Order Quantity (EOQ) methods (Nahmias, 2009) which minimize the total cost of ordering and holding inventories by making every attempt to purchase materiel under indefinite delivery and indefinite quantity (IDIQ) contracts, which reduces order quantity and delivery times. In 2006, DLA began placing many of the consumable items on long-term contracts in order to allow for faster order processing by reducing acquisition lead times. DLA began initiatives to develop relationships with suppliers, which in addition to allowing for streamlined and simplified purchasing of items on long-term contracts, also provided the means for information sharing with suppliers as well as enabling the Military Services to leverage their buying power.

1. DLA SUPPLY-CHAIN MANAGEMENT PROCESS

DLA manages almost every consumable item the Military Services need to operate, through three supply centers located at Columbus (Ohio), Philadelphia (Pennsylvania), and Richmond (Virginia). When Army determines there is an inventory requirement, a requisition is submitted to one of the DLA supply centers (see Figure 1).

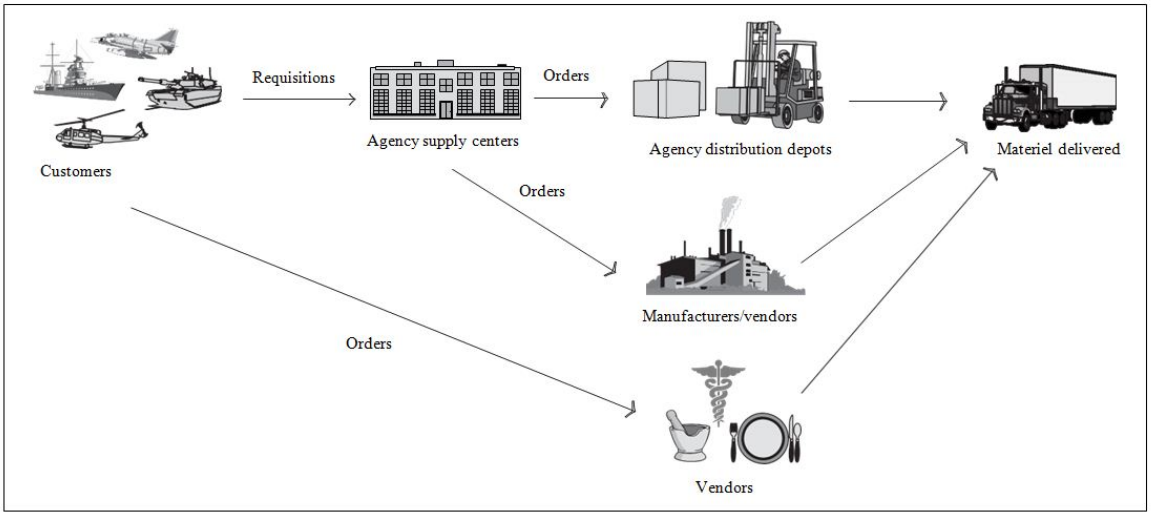

Figure 1. DLA's Supply-Chain Management Process (From GAO, 2003)

Requisitions are processed by DLA Transaction Services in accordance with the Military Standard Requisitioning and Issue Procedures (DLM 4000.25-1). DLA Transaction Services utilizes various means to process requisitions by electrical communications, mail, telephone, courier, and DOD EMALL. Requisitions for Army's secondary inventory spare parts are submitted via electrical communications through LMP.

In addition to providing a means to process requisitions, DOD EMALL provides tracking capabilities for all DLA requisitions and orders as well as visibility of all current assets. Once a requisition is received, it is determined whether the on-hand quantity will meet the requirement. A simple query on the NIIN displays the quantity on hand, referred to as "UNRESTRICTED/ RESTRICTED ASSETS", as well as other information including the standard unit price (see Figure 2).

Figure 2. NSN General Information

The Acquisition Advice Code (AAC) is a one-position alpha-numeric code which indicates how and under what restrictions an item will be acquired. The consumable

items supported by ECBC are typically coded either “D” or “Z” as shown in Figure 2, which indicates either “DoD INTEGRATED MATERIEL – MANAGED, STOCKED, AND ISSUED – Issue, transfer, or shipment is not subject to specialized controls other than those imposed by the Integrated Materiel Manager/Service supply policy” or “Insurance/Numeric Stockage Objective Item. Normal quantity stocked.” These items are all centrally managed, stocked, and issued, and all requisitions for these items must contain the fund citation required to acquire the item. All AAC codes are shown in Table 1.

AAC	REMARKS
A	Service Regulated. Issue, transfer, or shipment controlled above ICP level
B	ICP Regulated. Issue, transfer, or shipment controlled by ICP
C	Service/Agency Managed. No special controls required
D	DOD Integrated Materiel Manager (IMM) Stocked and Issued. No special controls
E	Other Service-Managed, Stocked and Issued. No special controls required
F	Fabricate or Assemble Non-stocked items.
G	GSA Civil Agency Integrated Materiel Managed, Stocked and Issued
H	Direct Delivery Under Central Contract (Non-stocked Items)
I	Direct Order from Central Contract/Schedule Non-stocked Items
J	Not Stocked, Centrally Procured Items
K	Centrally Stocked for Overseas Only. Main source is local purchase
L	Local Purchase Non-stocked Items
M	Restricted Requisitions – Major Overhaul
N	Restricted Requisitions – Disposal. Discontinued items
O	Packaged Fuels Non-stocked Items. DLA-managed and service regulated
P	Restricted Requisition – Security Assistance Program (SAP); items only for SAP
Q	Bulk Petroleum Products. DLA-managed
R	Restricted Requisition – Government Furnished Material (GFM)
S	Restricted Requisition – Other Service Funded; subject to specialized controls
T	Condemned Non-stocked Item. Not authorized to be purchased, issued, or used
U	Lead-Service Managed. Provides procurement, disposal, and single-submitter functions
V	Terminal Item. Item in stock but no future purchases authorized
W	Restricted Requisitioning – Special instructions apply non-stocked item
X	Semi-Active Item – No replacement; non-stocked item
Y	Terminal Item (Non-stocked Items). Further procurement not authorized
Z	Insurance/Numeric Stockage Objective Item. Normal quantity stocked

Table 1. Acquisition Advice Codes

The agency distribution depots with quantity on hand may be determined by clicking on Stock On Hand in the lower left menu. Codes used to represent the 26 DLA distribution depots are shown in Table 2.

	DLA DEPOTS
DDAG	Albany, GA
DDAA	Anniston, AL
DDBC	Barstow, CA
DDCN	Cherry Point, NC
DDCO	Columbus, OH
DDCT	Corpus Christi, TX
DDHU	Hill, UT
DDJF	Jacksonville, FL
DDNV	Norfolk, VA
DDOO	Oklahoma City, OK
DDPH	Pearl Harbor, HI
DDPW	Puget Sound, WA
DDRT	Red River, TX
DDRV	Richmond, VA
DDMA	Richmond, VA
DDDC	San Diego, CA
DDJC	San Joaquin, CA
DDSP	Susquehanna, PA
DDTP	Tobyhanna, PA
DDWG	Warner Robins, GA
DDDE	Germany
DDDK	Korea
DDGM	Guam, Marianas
DDKS	Kuwait, Southwest Asia
DDSI	Sigonella, Italy
DDYJ	Yokosuka, Japan

Table 2. DLA Distribution Center Codes

If there is sufficient inventory on hand, an order is placed by DLA to the distribution center(s) and the items are delivered to the customer. If there is not sufficient inventory on hand, a procurement action is initiated by DLA and an order placed with a manufacturer or vendor to deliver the items to the customer. DOD EMALL also provides the ability for customers to order some items directly from a

vendor, though DLA is generally the only entity authorized to buy secondary spare parts items on behalf of the Military Services.

2. INVENTORY REQUIREMENTS DETERMINATION

Historically, the Army's demand forecasts have been inaccurate, largely due to accuracy and timeliness of demand data. In October 2008, the Army issued guidance to item managers to set a forecast period using the previous 12 months of demand data in lieu of the previous 24 months to better account for changes in force levels and the resulting demands. The guidance further directed the item managers to use the readiness portion of the Army Operations Update, which reflects the actual quantities of weapon systems as reported by commanders, to update their forecast models to match actual quantities of items being used in Southwest Asia (GAO, 2009).

The U.S. Army prescribes guidance and procedural instructions for computing requirements for its secondary items inventory. Army Item Managers are responsible for developing inventory management plans for their assigned items, including the coordination of all purchase and repair decisions. In order to determine the appropriate inventory levels, Army uses a cost differential model which is based on several variables including procurement costs, holding costs, frequency of demand, implied stockage cost, and the probability of future demand (GAO, 2009). The maximum quantity of an item that may be on hand or on order at any given time is known as the "Quantity Requisitioning Objective" (Q RO) and consists of operating, safety, and order ship-time (OST) levels. The operating level is the quantity of stock needed to sustain operations in the interval between receipt of a replenishment shipment and submission of another replenishment requisition. The safety level is the quantity required to sustain operations in the event the demand rate changes unusually or the OST becomes longer than expected. OST level is the quantity of stock required to sustain operations between the time a replenishment requisition is submitted and the resulting materiel receipt is posted to the account. When the combined total of on-hand and on-order inventory for an item drops to a threshold level (reorder point), the Item Manager may submit a requisition for additional inventory of that item. The reorder point includes both operating requirements

and acquisition lead time requirements (Q ROP = Q OSTL + Q SL) and is determined by taking the quantity of stock on hand (Q OH), adding it to the due-in quantity (Q DI), then subtracting the due-out quantity (Q DO); if Q OH + Q DI – Q DO <= Q ROP, order more stock.

At TACOM, Item Managers perform demand planning as well as procurement requests in LMP. The Item Managers analyze historical demand data and make edits as necessary within the demand planning function in LMP. Any known future demand is combined with historical demand to forecast future requirements. For Reset or Repair programs, the Item Manager loads the Repair Bill of Materials (RBOMs) in LMP to ensure the secondary parts are included in the future requirements. LMP tracks and monitors supply at each Army Depot and automatically submits a requisition to DLA when the reorder point is reached.

Currently, DLA does not have any "Item Managers," but rather the Item Management process has been broken down into three different functions: Demand Planner, Supply Planner and Customer Account Specialist. The Demand Planners set their inventory reorder points for all stocked items (Acquisition Advice Code D) based historical demand coupled with input from Special Program Requests (SPRs) they receive from Army. Most SPRs for ECBC supported secondary consumable items are issued quarterly by TACOM to cover Army Depot requirements, usually 1 to 2 years out. SPRs cannot be within the procurement lead time, and thus are not typically used to relay the Army Reset program requirements since those requirements are not known far enough in advance. In addition to SPRs, DLA may receive other known future requirements via email, i.e., Pine Bluff may send FY projections to DLA based on projected workload requirements due to Army Reset and Repair programs. DLA uses software called Manugistics, currently owned and distributed by JDA, to manage their inventories. Manugistics uses 1 of 5 algorithms, which are automatically chosen based on demand pattern and quantity, to forecast future demand. Additionally, the Demand Planners analyze and validate any spikes (1 time instances) or surges (2-3 month occurrences).

D. CHAPTER SUMMARY

ECBC serves as the Engineering Support Activity (ESA) for numerous Chemical-Biological items, providing advice on market research and company capabilities, testing and inspection, and other technical areas as well as assuring the Technical Data Packages (TDPs) are accurate and all documentation current. Between August 2009 and December 2010, item management responsibilities for most consumable items supported by ECBC were transitioned from TACOM to the Defense Logistics Agency (DLA). Whereas TACOM provided built-in administrative lead time for the acquisition IPTs to review the procurement packages, including the TDPs, DLA does not. To ensure DLA gets correct Product Data for procurement of the consumable parts, an agreement was signed between AMC and DLA to require DLA to come to ECBC for the product data every time they need to procure parts and to require ECBC to provide the data in a timely manner (often within 15 calendar days).

DLA manages almost every consumable item the Military Services need to operate through three supply centers and 26 distribution centers (Depots). DLA Demand Planners use historical demand combined with known future requirements from Army Depot Special Program Requirements and other correspondence to forecast demand.

Army's LMP tracks and monitors supply at each Army Depot and automatically submits a requisition to DLA when the reorder point is reached. LMP is also used by production sites, i.e., Pine Bluff Arsenal, to submit requisitions to DLA for parts when a requirement exists.

Once a requisition is received by DLA, it is determined whether the on-hand quantity will meet the requirement. If there is sufficient inventory on hand, an order is placed by DLA to the distribution center(s) and the items are delivered to the customer. If there is not sufficient inventory on hand, a procurement action is initiated by DLA and an order placed with a manufacturer or vendor to deliver the items to the customer.

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III. RELATED RESEARCH

A. INTRODUCTION

Forecasting demand for military spare parts, whether consumable or reparable, is an extremely complex and widely studied field. U.S. Army inventory supply systems typically follow a “just in case” strategy which involves producers carrying large inventories in case higher demand has to be met. As reported by Nahmias (2009), in a Just-in-Time (JIT) inventory strategy, supply is coordinated with the demand and the optimal amount of inventory held at any time. Within a JIT inventory system, items are typically ordered more frequently and in smaller quantities, producing smoother demand patterns.

As reported by Unlu (2001), there are a wide variety of stochastic forecasting models available, which focus completely on historical demand patterns. Though there is no clear consensus as far a one best model or method to use, past research does indicate that specific methods may be better suited for certain demand patterns. The results of the literature review and the recommendations of a number of researchers in the field will be discussed in the following paragraphs.

B. SUMMARY OF LITERATURE REVIEW

A review of past research in the field of inventory control, including demand forecasting models and methods for weapon system items as well as just-in-time inventory systems was conducted. This complex field has been widely studied, with no consensus as far as one best model or method to use. As reported by Wetherington (2010), some researchers found no statistical differences in techniques used, while other researchers did report “best” methods.

Unlu (2001) described a number of stochastic forecasting models which forecast demand by focusing completely on the historical demand patterns. Unlu (2001) further describes a methodology known as “focus forecasting”, which selects the “best” model based on forecast accuracy. To measure forecast accuracy, Unlu (2001) used the Mean-Square Error (MSE), which is the average of the square of the differences between the

actual demands and the forecasted demands. Unlu (2001) concluded that the "focus forecasting" methodology worked best for items with at least three quarters of demand within a period of eight quarters, whereas the four-quarter moving average model worked best for items with intermittent demand.

Bachman and Kruse (1994) concluded that exponential smoothing of historical demand provided the "best" method for forecasting the demand of consumable weapon system items. Exponential smoothing, also referred to as Exponentially Weighted Moving Average (EWMA), gives weight to past data and the weight varies geometrically with the increasing age of the data (most recent data is weighted higher than older data). Jaw (1995) modified this method to incorporate provisions for trend correction by first using EWMA to project the average level and then again to project a level for the trend. Jaw (1995) concluded that this adjusted EWMA provided the "best" method for forecasting demand when the demand data contains seasonal or trend components. Further, Meadows (1996) found that the noise-to-signal ratio can be used to select the smoothing constant in EWMA for a given set of demand data. Meadows (1995) defined the noise as the error in a forecast and the signal as the change in the forecast from the last period. Meadows (1996) determined this adjusted EWMA method provides a good forecast, minimum data storage requirement, and an automatic way to select the smoothing constant, specifically for "lumpy" demand. Lumpy demand patterns are typical of many demand patterns for consumable military items and are characterized by low volume and a high degree of uncertainty as to when and at what level demand will occur.

Stochastic forecasting models are only effective when the demand pattern represents a process that is under statistical control. Demand varies over time and the analysis of this variation is used as a basis to forecast future demand. According to Shewhart (1931), variation in any process characteristic, i.e., demand, has two types of causes: common causes and special causes. Common causes are those that are inherently part of the process and affect everyone working within the process. Special causes are those causes which are not part of the process all of the time or do not affect everyone, but arise due to special circumstances (Shewhart, 1931). There are two types of special

causes for variability: transient and persistent (Hawkins & Olwell, 1997). Transient causes are present for one period of time or may be intermittent, whereas persistent causes are present until detected and corrected. A process whose outcomes are affected by both common and special causes is considered unstable because the magnitude of variation between time periods is unpredictable (Nolan & Provost, 1990). A process that has only common causes affecting the outcomes is considered stable and in a state of statistical control. Deming (1986) provides several benefits of a stable process: 1) it performance is predictable which provides a rational basis for planning; 2) costs and quality are predictable; 3) productivity is maximized and costs minimized; 4) the effect of changes in the process can be measured with greater speed and reliability.

The distinction between common and special causes can be made using control charts. Shewhart developed a control chart to determine whether variation in a process is dominated by common or special causes. Shewhart's control chart consists of three lines and points plotted on a graph (see Figure 3).

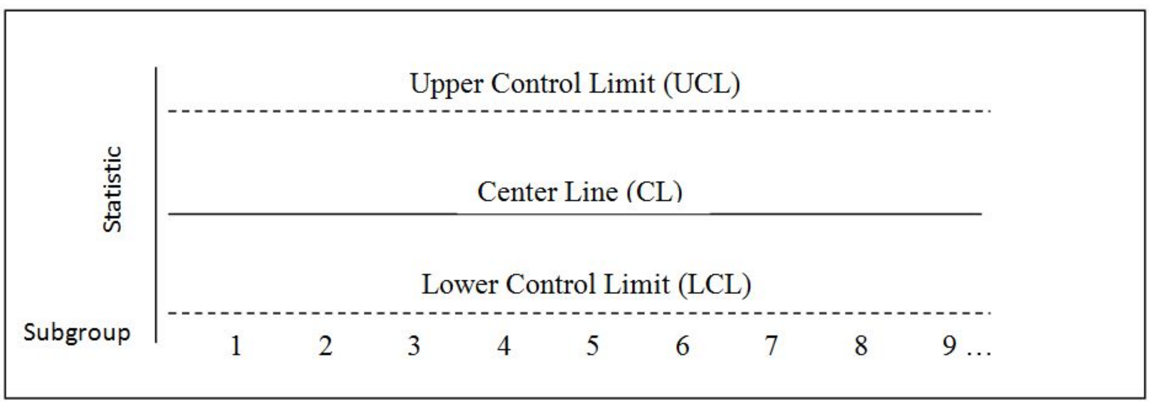

Figure 3. Shewhart Control Chart

The centerline is the average of the data or statistic which is plotted and the control limits bound the variation in the statistic due to common causes. The presence of any points outside the control limits indicates the existence of special causes. Shewhart's control charts are sensitive to detecting relatively large isolated shifts in a process due to special causes, i.e., of the order of 1.5σ or above. Cumulative Sum (CUSUM) charts and Exponentially Weighted Moving Average (EWMA) charts are primarily used to detect

smaller persistent shifts in a process. Wetherington (2010) compared and evaluated CUSUM and EWMA control charts as a method to detect changes in demand for aviation spares and concluded that though EWMA charts tended to be slightly slower in providing alarms, they were much easier to set up and that overall EWMA charts are more efficient to use.

As reported by Hicks (1997) and Wetherington (2010), there are a number of "causal" factors which effect demand for weapons system items. For the consumable parts managed by ECBC, these factors may include operational environment, tempo, the number of systems in use (density), and troop levels deployed in the Middle East. Simple regression may be used to find any correlation between the demand for consumable parts and any single causal factor, i.e., troop levels deployed.

Just-in-Time (JIT) is a production strategy developed within the Japanese auto industry as a way to focus on continuous improvement of manufacturing processes and to eliminate waste. This involves making up a system that will thoroughly eliminate waste by assuming that anything other than the minimum amount of equipment, materials, parts, and workers (working time) which are absolutely essential to production are merely surplus that only raises cost (Sugimori, Kusunoki, Cho & Uchikawa, 2007). The primary goals of JIT are to reduce inventory and associated storage costs, to reduce waste, and to raise the quality of the products. The less capital required to store and carry inventory, the less waste and the better optimization of transportation and logistics operations. Large inventories not only tie up a great deal of capital, but also devour assets and labor.

The closer one gets to operating in a true JIT environment, the more responsive supply is to demand (UPS, 2005). Within JIT, inventory is considered undesirable because it hides production inefficiencies, quality and productivity problems, and adds unnecessary cost to the production operations due to carrying costs. The biggest challenge within a JIT inventory system is balancing the goals of avoiding stock outs while minimizing inventory costs. Managing a JIT inventory system requires significant coordination between everyone in the supply chain. If buyers fail to adjust quickly to increased demand or if suppliers have distribution problems, there is an increased risk of stock outs. Shortening lead time, which is an important element in any inventory

management system, can lower the safety stock levels and reduce the loss caused by stock outs. An integrated inventory model can be utilized to minimize the sum of the ordering/setup cost, holding cost, quality improvement and crashing costs by simultaneously optimizing the order quantity, the lead time, the process quality and the number of deliveries (Yang & Pan, 2004).

Inventory management systems are classified as either "push" or "pull" systems. In a "push" system, decisions concerning how material will flow through the system are made centrally, and based on these decisions material is "pushed" to the next level of the system. An example of a "push" inventory management system is a Material requirements planning (MRP) system. In a "pull" system, production is initiated at one level as a result of a request from a higher level and material is "pulled" through the system. As a "pull" inventory management system, JIT has many advantages over MRP, but also requires better relationships with suppliers. The suppliers must be willing to absorb some uncertainty and adjust delivery quantities and timing of the deliveries to match production rates. The primary differences between JIT and conventional purchasing are shown in Table 3.

Conventional Purchasing	**JIT Purchasing**
1. Large, infrequent deliveries	1. Small, frequent deliveries
2. Multiple suppliers for each part	2. Few suppliers, single sourcing
3. Short-term purchasing agreements	3. Long-term agreements
4. Minimal exchange of information	4. Frequent information exchange
5. Prices established by suppliers	5. Prices negotiated
6. Geographical proximity unimportant	6. Geographical proximity important

Table 3. Characteristics of Conventional vs. JIT Purchasing (From Nahmias, 2009)

The EOQ (economic order quantity) model is the simplest and most fundamental of all inventory models and describes the important trade-off between ordering and holding costs. The objective is to choose the order quantity Q to minimize the average cost per unit time. The standard EOQ equation (1) is:

$$EOQ = \sqrt{\frac{2 * (AYDQ * OC)}{(UP * HC)}}$$

where

AYDQ	=	average yearly demand quantity for the item
OC	=	marginal order cost
UP	=	unit price of the item
HC	=	marginal holding cost as a percentage of unit price

The total average annual cost is given by equation (2):

$$G(Q) = \frac{(OC * AYDQ)}{Q} + (AYDQ * UP) + \frac{[(HC * UP) * Q]}{2}$$

where the three terms composing G(Q) are the annual setup cost, annual purchasing cost, and annual holding cost, respectively.

It is important to understand that though JIT can have many advantages, it is not always the best approach (Nahmias, 2009), particularly when the supply chain is subject to disruption or the setup cost per positive order placed is very high.

C. CHAPTER SUMMARY

Forecasting demand for military spare parts, whether consumable or reparable, is an extremely complex and widely studied field. The demand patterns vary greatly and are often "lumpy" for consumable items. Extensive research has been conducted over the past 40–50 years, and though there is no clear consensus as far a one best model or method to use, past research does indicate that specific methods may be better suited for certain demand patterns. The demand patterns for consumable military items are typically "lumpy" and are affected by several causal factors including deployment cycles in the Middle East. Since this thesis will focus on the inventory data for the secondary chemical-biological consumable items managed by ECBC, the author will analyze the effectiveness of Simple Regression and EWMA forecasting models to predict the demand of these items.

IV. RESEARCH ANALYSIS

A. INTRODUCTION

This thesis compares the effectiveness of Simple Regression and EWMA forecasting models to predict the demand of Chemical Biological consumable items, using the procurement history data for four specific items. Additionally, the author investigates the inventory policies and supply issues which currently exist at a customer's site and provides recommendations for improving the current processes in order to achieve smoother demand patterns.

B. ANALYSIS TECHNIQUES USED

1. Data Sets Used

The four data sets to be analyzed were determined by selecting "stocked" consumable items managed by ECBC for which DLA has requested a Technical Data Package at least one time during the past three years. "Stocked" items are those with Acquisition Advice Codes "D" or "Z". Specific selection criteria included past demand volume, item unit cost, percent of back orders, and lumpiness of past demand patterns. The four data sets were determined by selecting items which not only fit one of these specific criteria, but also for which there was at least eight quarters of demand. Sources of data included DOD EMALL, the Federal Logistics Information System (FLIS) and the Army's Logistics Information Warehouse (LIW).

a. Item Selection

Since the Consumable Item Transfer (CIT) initiative began for ECBC managed items in 2009, DLA has submitted 289 requests for Technical Data Packages (TDPs) for 246 consumable items, 180 of which are stocked items. A report was compiled using data from DoD EMALL and ECBC's Product Data Management (PDM) System for those 180 items to assist in the item selection process. A portion of the report is shown in Table 4.

Part Number	NIIN	DLA Case Number	Request Date	Date Completed	Days	AAC	# Reqs	# of Qtrs	Unit Price	Past demand	Stock Onhand	Back order Qty	Due In Qty
5-1-2796	014647839	DM_12_014647839	23-Jan-12	2-Feb-12	10	D	2920	20	$4.91	768744	62810	0	252435
5-1-3354	014424810	DSCP-FC-12-16210	3-Jan-12	11-Jan-12	8	D	92	10	$58.13	1528	18	255	1650
5-1-3502	014975069	DM_12_014975069	31-May-12	7-Jun-12	7	Z	15	6	$194.31	43	0	0	24
5-15-5490	001367182	DM_CIT_001367182	24-May-11	7-Jun-11	14	D	38	9	$33.10	190	0	0	0
5-19-6180	010523783	DM_12_010523783	12-Dec-11	14-Dec-11	2	D	55	10	$32.27	307	325	0	0
5-19-6411	010565283	DM_13_010565283	3-Oct-12	17-Oct-12	14	Z	9	6	$1,054.97	14	0	0	7
5-19-6696	011871029	DM_12_011871029	24-Jan-12	2-Feb-12	9	D	52	10	$304.48	73	93	0	0
5-19-8144	013384134	DM_12_013384134	8-Jun-12	22-Jun-12	14	Z	8	5	$1.36	2017	0	1886	3001
5-19-9700	013083656	DM_12_013083656	27-Jan-12	13-Feb-12	17	Z	3	3	$7,228.10	5	0	1	5
116-3-162	014669556	DM_12_014669556	14-Sep-12	27-Sep-12	13	D	155	10	$49.78	571	418	0	0
116-3-242	015588700	DM_12_015588700	10-Sep-12	24-Sep-12	14	Z	7	5	$311.85	26	0	18	23
116-3-47	010678680	DM_010678680	21-Mar-11	1-Apr-11	11	D	7	5	$528.57	33	24	0	0
116-3-94	001642688	DM_12_001642688	28-Feb-12	13-Mar-12	14	D	12	8	$548.05	20	0	2	11
116-4-40	015014384	DM_12_015014384	17-Sep-12	1-Oct-12	14	Z	13	5	$11.88	220	110	0	0
116-4-41	015014380	DM_12_015014380	10-Sep-12	24-Sep-12	14	D	94	12	$11.03	2171	0	227	2029
116-4-42	015014423	DM_12_015014423	17-Apr-12	27-Apr-12	10	D	30	8	$240.45	1416	0	12	108
13-12-111	010950092	DM_12_010950092	14-Aug-12	27-Aug-12	13	D	100	14	$223.85	518	160	0	71
13-12-176	012087115	DM_13_012087115	11-Dec-12	26-Dec-12	15	D	129	13	$250.19	1051	299	0	65
13-12-295	013309435	DM_12_013309435	20-Oct-11	8-Nov-11	19	Z	10	6	$121.06	86	28	0	35
13-12-305	013309436	DM_12_013309436	27-Mar-12	12-Apr-12	16	Z	20	6	$147.83	130	0	3	130

Table 4. DLA Requests for ECBC TDPs

Part number 5-1-1047 was selected due to having a large number of backorders (currently 7,167 units) with 17 quarters of historical demand. This item is the Side Voicemitter Assembly used on the M40/M42-Series Field Protective Masks. The Side Voicemitter Assembly does not typically require replacement in the field, only when the user cannot communicate through the voicemitter. The Side Voicemitter Assembly can be moved from one side of the mask to the other by the user to accommodate whether they are a left or right handed shooter. The mask port on the opposite side of the side voicemitter is used for the C2A1 canister filter. Though the side voicemitter assembly is part of the facepiece assembly performed at Pine Bluff Arsenal, Pine Bluff Arsenal has a standing contract with the vendor and does not submit requisitions to DLA for this item. As far as DLA is concerned, the demand for the side voicemitter is due to field maintenance and repair, and is not affected by the assembly of new facepieces, Reset, or CBERT missions.

Part number 5-19-6181-10 was selected due to having a moderate unit price ($484.55 per unit) with 14 quarters of historical demand. This item is an Air Duct Hose used primarily on the M265 Patriot Missile Installation Kit and the M10 Collective Protection Equipment. The air duct hose connects the Protective Entrance (PE) to the

protected enclosure/shelter for these systems, providing air flow from a Gas-Particulate Filter Unit (GPFU). The GPFU filters toxic gases and dust from incoming air to provide clean air for the protective entrance and the protected enclosure. The protective entrance provides a pressurized transition area between the enclosure and the outside contaminated zone allowing a user's decontamination to a suitable level in 5 minutes.

Part number 5-1-2796 was selected due to having the largest volume of past demand (768,744 units) with 20 quarters of historical demand. This item is a Head Harness Assembly used on the M40/M42-Series Field Protective Masks. The M40-series protective masks are currently the standard Army field mask, though they will be replaced during the next few years by the Joint Services General Purpose Mask (JSGPM). The M40A1 is issued to dismounted soldiers, while the M42A2 protective masks are used by Combat Vehicle Crewman and have the same components as the M40A1 with an additional built-in microphone for wire communication. The head harness is constructed of elastic webbing sewn to a rectangular head pad and secures the mask facepiece to the user's head. The elastic straps tend to lose their elasticity over time, requiring the harness to be replaced. The head harness is also replaced in the field when it is cut, torn or frayed, or has missing buckles or tabs. A new harness is required for each mask which is refurbished during Army Reset or Chemical Biological Equipment Repair Team (CBERT) missions or when each mask is sanitized due to transfer to another solider or turn-in as serviceable excess as well as during the assembly of all new facepieces.

Part number 5-1-1050-20 was selected due to an extremely variable ("lumpy") demand pattern with 17 quarters of historical demand. This item is the Deflector Post Subassembly used on the medium and large sizes of the M40/M42-Series Field Protective Masks. The Deflector Post Subassembly is part of the Airflow Deflector which is located inside the mask facepiece on the same side as the C2A1 canister and directs inhaled air over the eye lens to reduce fogging. The deflector post also supports the inlet valve disk and the inlet valve body, which allow filtered air to enter the mask assembly and prevents moist exhaled air from entering the C2A1 canister filter. Replacement of the Deflector Post Subassembly due to field level repair is not typical and

approximately 95% of the demand for this item is due to the assembly of new facepieces, Reset, or CBERT missions conducted by Pine Bluff Arsenal.

b. Data Sources

DOD EMALL is primarily used as a single entry point for DOD and Federal government customers to find and acquire items from either the commercial marketplace or government sources. Additionally, DOD EMALL provides Asset Visibility and Tracking Status capabilities, which provides the ability to view current inventories as well as track the status of all DLA orders. DOD EMALL is the site used by DLA item managers to receive, review, and process requisitions from their customers (DLIS, n.d.).

The Army's LIW is the Army's single authoritative source from which to obtain supply, maintenance, force structure, asset visibility and readiness information. LIW integrates legacy systems data with the data from modern Army Enterprise Resource Planning (ERP) systems, i.e., Global Combat Support System-Army (GCSS-Army), Logistics Modernization Program (LMP) and Army Enterprise Systems Integration Program (AESIP) (AMC, 2011).

IHS Haystack Gold combines and cross-references information on millions of items in the U.S. Federal Supply Catalog, as well as U.S. Navy, Army, Air Force, Marine Corps, Coast Guard and related government, military, and commercial databases, providing the world's largest collection of information on U.S. Government procurements and stocked parts (IHS, n.d.).

c. Data Features

A summary of the descriptive statistics for the quarterly demand for each selected part is shown in Table 5.

PN	N	Mean	SE Mean	StDev	Min	Q1	Median	Q3	Max
5-1-1047	9	2027	212	794	47	609	1730	2205	2468
5-19-6181-10	14	45.8	10.3	38.7	9.0	15.8	25.5	71.8	120.0
5-1-2796	13	50748	11786	42495	1874	25401	38723	75636	166960
5-1-1050-20	10	32154	11834	37422	608	4753	19882	47777	113721

Table 5. Summary of Descriptive Data for Quarterly Demand

A significant portion of the demand for items 5-19-6181-10, 5-1-2796 and 5-1-1050-20 comes from single sources. 68% of the demand for 5-19-6181-10 originated from Letterkenny Army Depot, while 95% of the demand for 5-1-1050-20 and 86% of the demand for 5-1-2796 originated from Pine Bluff Arsenal.

The requisition data for part 5-1-1050-20 is shown in Figure 4. The number of parts varied between 1 and 39,160 per requisition. Additionally, there were numerous occasions when the same customer submitted multiple requisitions on the same day.

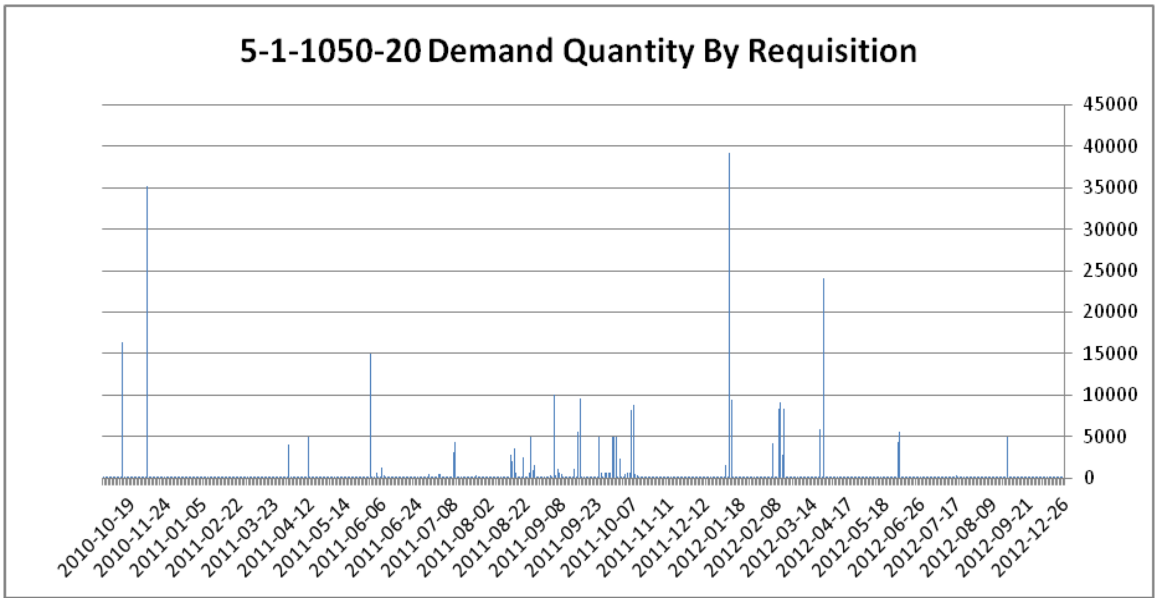

Figure 4. Requisitions Processed by DLA for 5-1-1050-20 (DoD EMALL)

The quarterly demand for 5-1-1050-20 shows a large amount of variation with no obvious trend or seasonal affects (see Figure 5). This was confirmed by running t Tests and generating Boxplots to compare the demand during the first two quarters of each Fiscal Year (FY) with the demand during the last two quarters of each FY (see Table 6 and Figure 6). For the t Test, the p-value of the observed statistic was greater than 0.05 (α), so there is no significant difference in demand between the two sets of data (no seasonal affect). Comparing the boxplots shows there is significant overlap which also indicates the data sets are similar. Similar tests run for the other three data sets produced similar results.

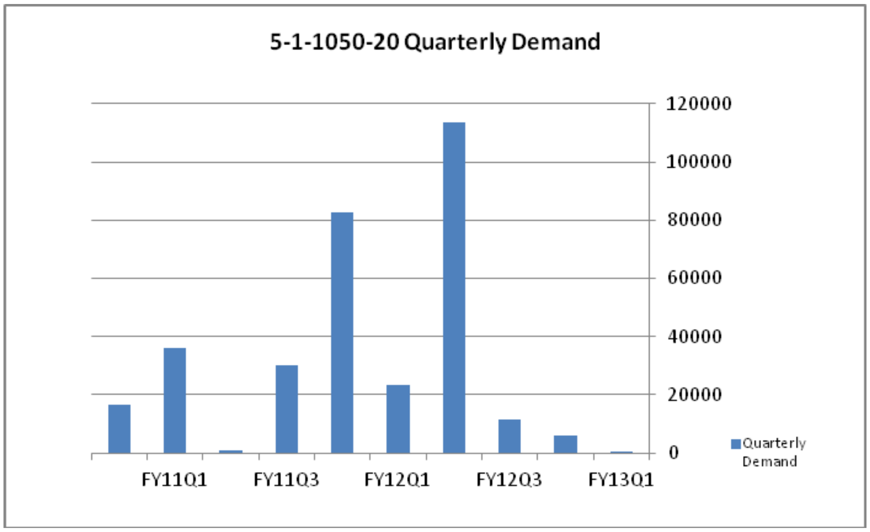

Figure 5. Quarterly Demand Data for 5-1-1050-20

	Q12	***Q34***
Mean	43543.5	32557
Variance	2399872463	1215142581
Observations	4	4
Pooled Variance	1807507522	
Hypothesized Mean Difference	0	
df	6	
t Stat	0.365455331	
P(T<=t) one-tail	0.363654611	
t Critical one-tail	1.943180274	
P(T<=t) two-tail	0.727309222	
t Critical two-tail	2.446911846	

Table 6. Two-Sample Assuming Equal Variances (5-1-1050-20)

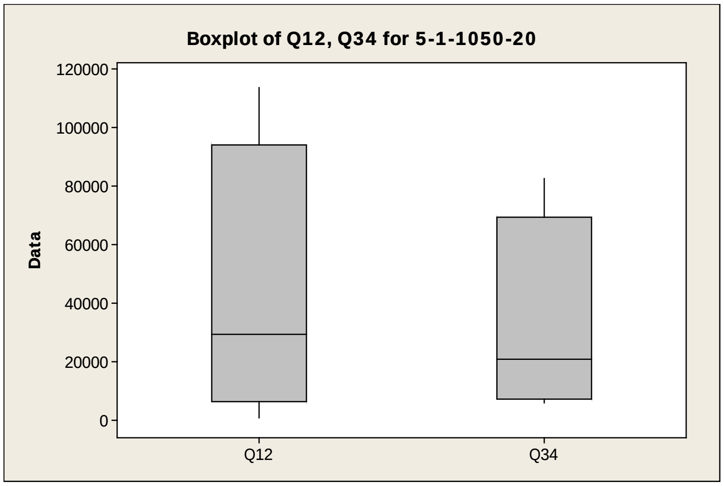

Figure 6. Boxplots of Q12 and Q34 for 5-1-1050-20

Average quarterly troop levels in Afghanistan and Iraq have been trending downward the past 14 quarters as shown in Figure 7. Table 7 shows there is no correlation between the average quarterly troop levels and the quarterly demand, with adjusted r-squared values ranging from 2.2% to 12%.

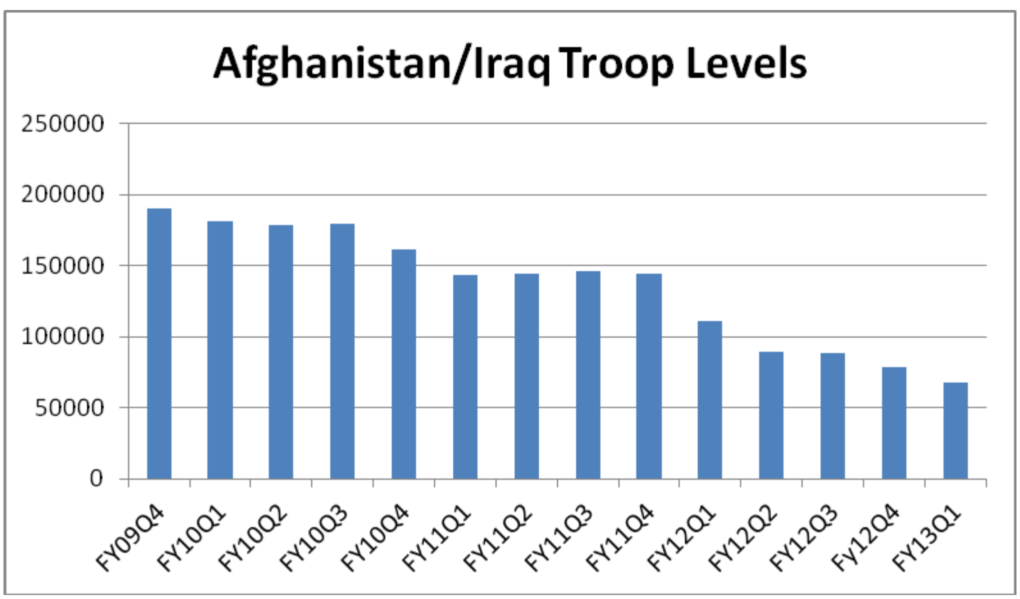

Figure 7. Afghanistan/Iraq Average Quarterly Troop Levels

Regression Statistic	Part Number			
	5-1-1047	5-19-6181-10	5-1-2796	5-1-1050-20
Multiple R	0.183485583	0.064063591	0.32149234	0.06724102
R Square	0.033666959	0.004104144	0.10335733	0.00452135
Adjusted R Sq	-0.10438062	-0.07888718	0.02184436	-0.1199135
Standard Error	349.4434882	43416.8057	39885.0258	39602.4789
Observations	9	14	13	10

Table 7. Regression Statistics for Demand versus Troop Levels

2. Forecasting Methods Analyzed

Each data set was used to analyze and compare the effectiveness of the use of Simple Regression Analysis and EWMA forecasting models to predict the demand for the associated Chemical Biological consumable item.

a. Simple Regression Analysis

Simple regression assumes that a basic relationship exists between two variables and can be represented by some function $Y = f(X)$, where Y is referred to as the dependent variable and X is referred to as the independent variable. Simple regression is a straight-line method and is typically used when a trend is suspected in a time-series. If we have n paired data points (x_1,y_1), (x_2,y_2),…, (x_n,y_n), for the two variables X and Y and assume that y_i is the observed value of Y when x_i is the observed value of X, we may assume that a relationship exists between X and Y that can be represented by the straight line $Y' = a + bX$, where Y' is the predicted value of Y. The goal is to find the values of a and b which will produce a trend line which gives the best fit of the data. The values of a and b are generated by minimizing the sum of the squared distances between the trend line and the data points.

When using Simple Regression Analysis to forecast demand, the independent variable corresponds to time and the dependent variable to the demand. The optimal values of a and b are given by equation (3):

$$b = S_{xy}/S_{xx}$$

and equation (4)

$$a = \bar{D} - b(n + 1)/2,$$

where equation (5) and equation (6)

$$S_{xy} = n\sum_{1=1}^{n} iD_i - \frac{n(n+1)}{2}\sum_{i=1}^{n} D_i$$

$$S_{xx} = \frac{n^2(n+1)(2n+1)}{6} - \frac{n^2(n+1)}{4}$$

and $\bar{D}$ is the arithmetic average of the observed demand during periods 1,2,…,n. The forecasted demand for period t, D_t, is then be given by equation (7):

$$D_t = a + bt$$

Simple regression compensates for trend effects but does not follow seasonal effects. When demand is related in time from one period to the next, autocorrelation occurs which violates the assumption of independence required to produce a valid regression forecast. Regression analysis expects fluctuations in demand to be independent of each other. The best test for autocorrelation is to generate an autocorrelation plot of the residuals. Most of the residual autocorrelations should fall within the 95% confidence bands around zero, which are located at roughly $\pm \frac{2}{\sqrt{n}}$, where n is the sample size.

Violations of linearity will produce very inaccurate forecasts, especially when you extrapolate beyond the range of the sample data. Nonlinearity is usually most evident in a plot of the observed versus forecasted demand. The points should be symmetrically distributed around a diagonal line. Evidence of a “bowed” pattern indicates that the model makes systematic errors whenever it is making unusually large or small predictions.

b. Exponentially Weighted Moving Average (EWMA)

Exponentially Weighted Moving Average (EWMA) is a statistical method of forecasting future demand which gives weight to past data and the weight varies geometrically as the age of the data increases. The most recent data is weighted higher than the older data. EWMA combines the most recent forecasted demand with the most recent actual demand. The weight applied to each period in terms of an exponential relationship is set by selecting a constant value α between 0 and 1, inclusive. EWMA is also referred to as Exponential Smoothing. The simplest mathematical form of EWMA is equation (8):

$$Y_t = Y_{t-1} + \alpha(X_{t-1} - Y_{t-1}) = \alpha X_{t-1} + (1-\alpha)Y_{t-1}$$

where:

α is a weight (smoothing constant) that has a value between 0 and 1, inclusive

Y_t = forecasted demand for period t

X_{t-1} = actual demand for period t-1

n = Number of time periods included in the moving average

A higher value for α gives greater weight to more recent periods. If α =1, the new forecasted demand is simply the actual demand for the previous period. Since this equation is recursive, it can be expanded to equation (9):

$$Y_t = \sum_{1=1}^{\infty} (1-\alpha)^i \alpha X_{t-i-1}$$

EWMA is easy to calculate and implement, but will always lag behind any trend. EWMA assumes a stationary time series in which each observation can be represented by a constant plus a random fluctuation. The unknown constant corresponds to the mean of the series and the random error has a mean of zero and variance σ^2.

c. Evaluation of Forecasts

The accuracy of each forecast technique will be evaluated by calculating and comparing the mean absolute deviation (MAD) , the mean squared deviation (MSD), and the mean absolute percentage error (MAPE) for each forecast, given by the following equations (10) (11) and (12):

$$MAD = \left(\frac{1}{n}\right)\sum_{1=1}^{n}|e_i|$$

$$MSD = \left(\frac{1}{n}\right)\sum_{i=1}^{n}e_i^2$$

$$MAPE = \left[\left(\frac{1}{n}\right)\sum_{i=1}^{n}|e_i/D_i|\right] \times 100$$

where :

$\mathbf{e_i}$	=	forecast error observed in period **i**
$\mathbf{D_i}$	=	observed demand for period **i**
n	=	number of observed periods

C. SPARE/REPAIR PARTS PROCUREMENT FORECASTING ANALYSIS

Simple Regression and EWMA forecasting methods were compared using each selected data set to determine which method is the most effective for predicting the demand of Chemical Biological consumable items. The software Minitab was chosen to perform the statistical analysis.

1. Results of Analysis for Consumable Item 5-1-1047

A general regression analysis was run to determine whether there was a trend in the data with respect to time. The results of the analysis are shown in Table 8 and a trend analysis plot in Figure 8.

General Regression Analysis: 5-1-1047 Qtr Demand versus Qtr				
Regression Equation				
5-1-1047 Qtr Demand = 2067.97 - 8.15 Qtr				
Coefficients				
Term	**Coef**	**SE Coef**	**T**	**P**
Constant	2067.97	257.667	8.02576	0.000
Qtr	-8.15	45.789	-0.17799	0.864
Summary of Model				
S	**R-Sq**	**R-Sq(adj)**	**PRESS**	**R-Sq(pred)**
354.677	0.45%	-13.77%	1465788	-65.71%

Table 8. General Regression Analysis for 5-1-1047

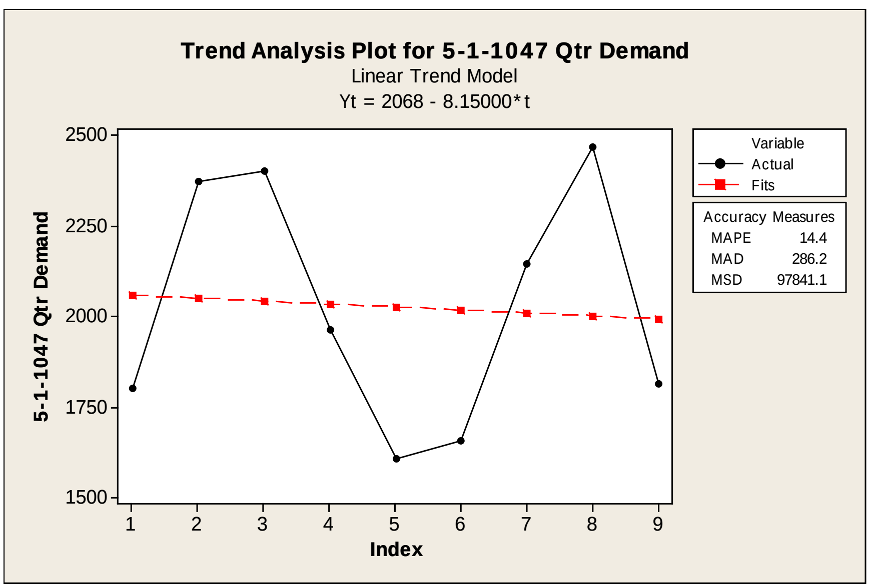

Figure 8. Trend Analysis Plot for 5-1-1047 Quarter Demand

The P value (0.864) for Qtr is greater than 0.05 which indicates the slope is not statistically significant and thus we may assume the slope is 0. The P value (0.000) for

Constant is less than 0.05 which indicates the constant is statistically significant. The adjusted R-squared value -13.77% indicates that less than 14% of the variation is explained by which quarter and more than 86% is explained by something else. CUSUM and EWMA Charts were generated to see whether the mean changes over time as shown in figures 9 and 10.

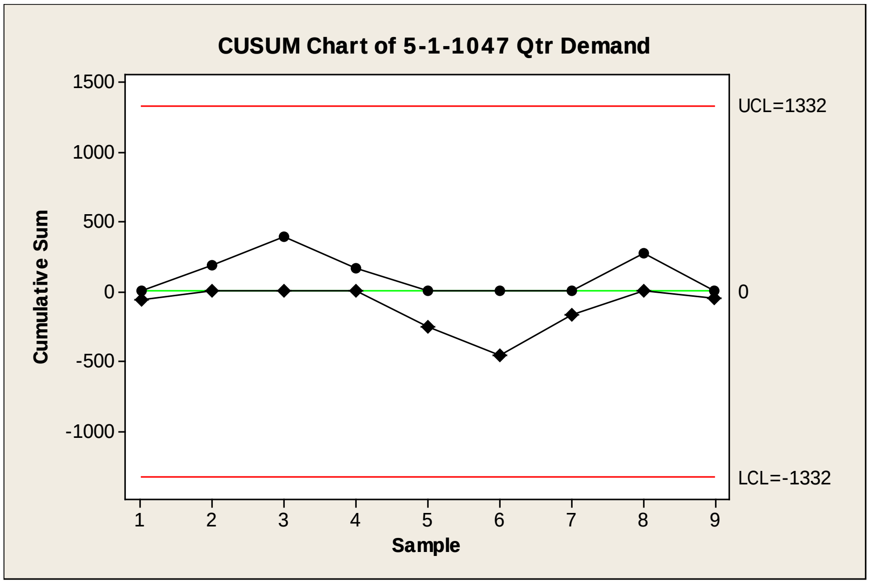

Figure 9. CUSUM Chart for 5-1-1047

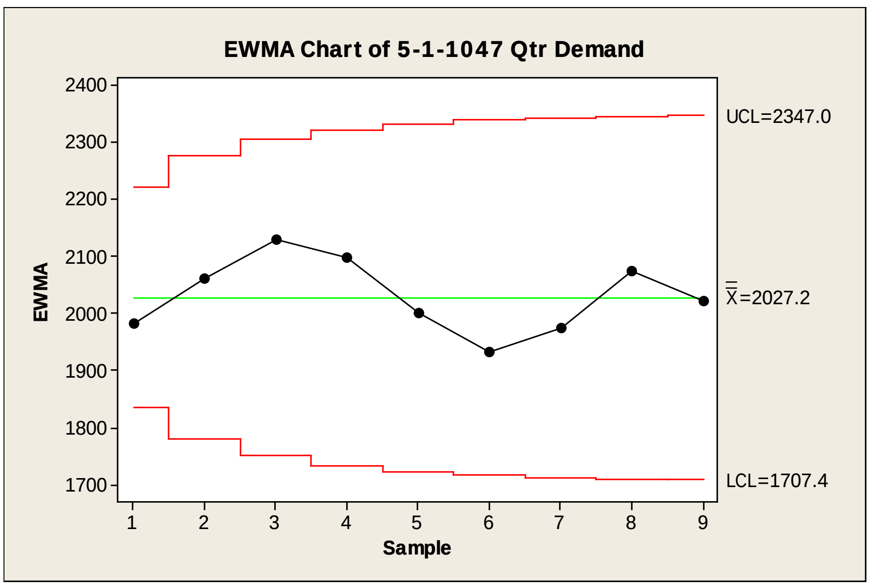

Figure 10. EWMA Chart for 5-1-1047

The regression analysis indicates that the average demand does not change over time, so the most likely value of demand during any quarter is the mean, 2027.2. Assuming slope=0 and the demand is always 2027.2, the calculated measures of error are: MAPE=14.39, MAD=286.24, and MSD=98283.95.

A single exponential smoothing plot was generated for 5-1-1047 using smoothing constant $\alpha = 0.2$ as shown in Figure 11. The forecasted demand for quarter 10 is 2044.

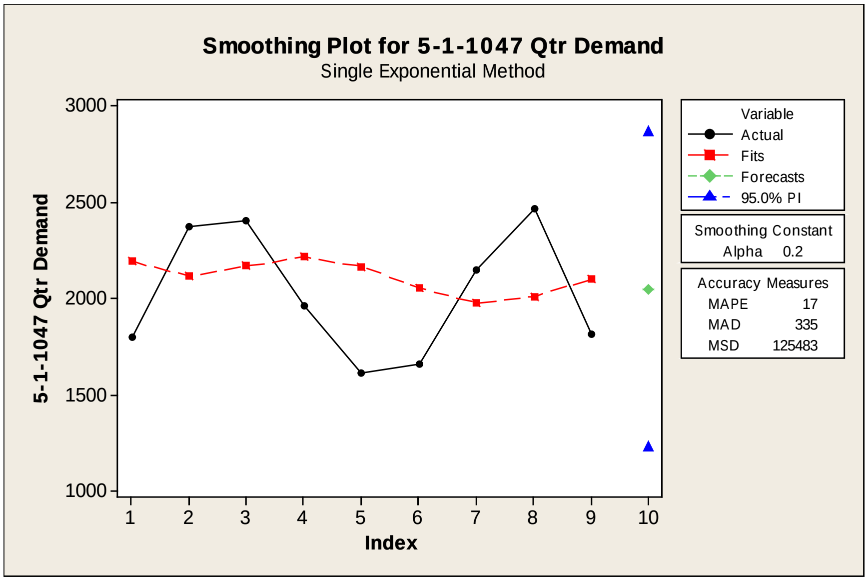

Figure 11. Single Exponential Smoothing Plot for 5-1-1047

Neither simple regression nor EWMA produce accurate forecasts for 5-1-1047. All three measures of error indicate that simply ordering the mean (2027) every quarter, is more accurate than using EWMA forecasts.

2. Results of Analysis for Consumable Item 5-19-6181-10

A general regression analysis was run to determine whether there was a trend in the data with respect to time. The results of the analysis are shown in Table 9 and a trend analysis plot in Figure 12.

General Regression Analysis: 5-19-6181-10 Qtr Demand versus Qtr				
Regression Equation				
5-1-19-6181-10 Qtr Demand = 37 + 1.17143 Qtr				
Coefficients				
Term	**Coef**	**SE Coef**	**T**	**P**
Constant	37.000	22.5491	1.64087	0.127
Qtr	1.1714	2.6483	0.44234	0.666
Summary of Model				
S	**R-Sq**	**R-Sq(adj)**	**PRESS**	**R-Sq(pred)**
39.9439	1.60%	-6.60%	24449.7	-25.65%

Table 9. General Regression Analysis for 5-19-6181-10

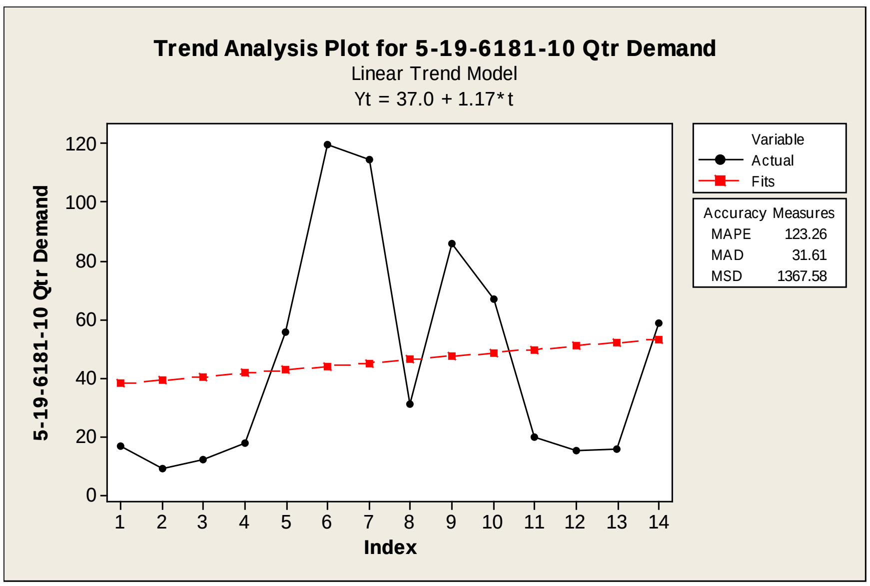

Figure 12. Trend Analysis Plot for 5-19-6181-10

The P value (0.666) for Qtr is greater than 0.05 which indicates the slope is not statistically significant and thus we may assume the slope is 0. The P value (0.127) for Constant is also greater than 0.05 which indicates the constant is not statistically significant. The adjusted R-squared value -6.60% indicates that less than 7% of the variation is explained by which quarter and more than 93% is explained by something else. CUSUM and EWMA Charts were generated to see whether the mean changes over time as shown in figures 13 and 14.

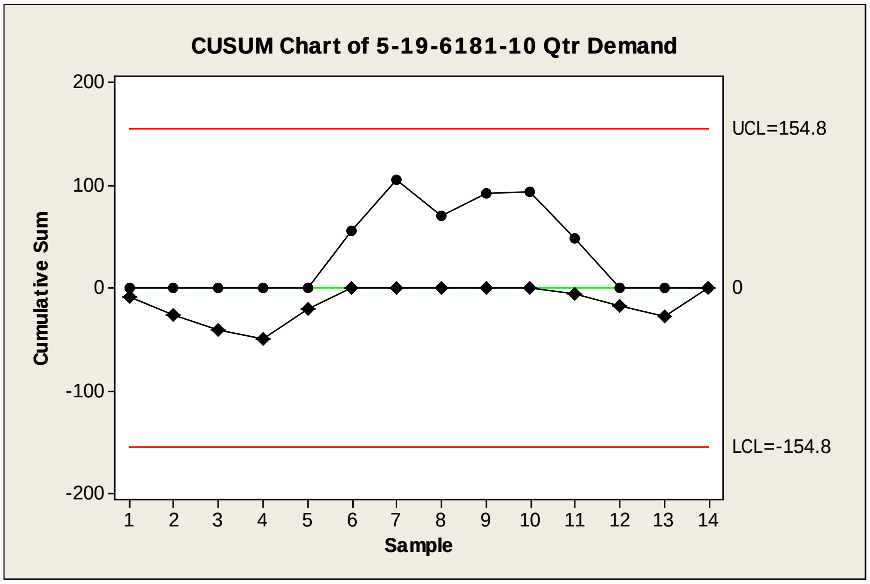

Figure 13. CUSUM Chart for 5-19-6181-10

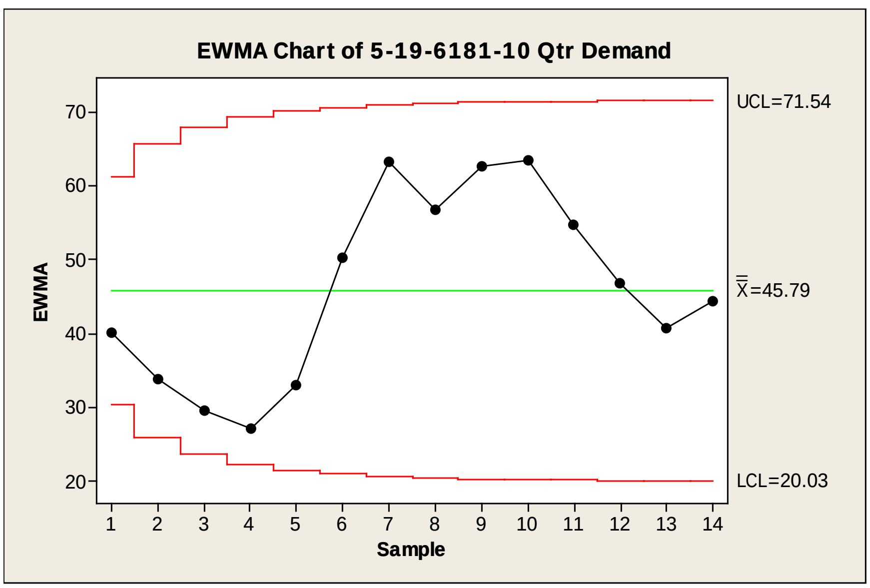

Figure 14. EWMA Chart for 5-19-6181-10

The regression analysis indicates that the average demand does not change over time, so the most likely value of demand during any quarter is the mean, 45.8. Assuming slope=0 and the demand is always 45.8, the calculated measures of error are: MAPE=130.27, MAD=32.61, and MSD=1389.88.

A single exponential smoothing plot was generated for 5-19-6181-10 using smoothing constant α = 0.2 as shown in Figure 15. The forecasted demand for quarter 15 is 42.89.

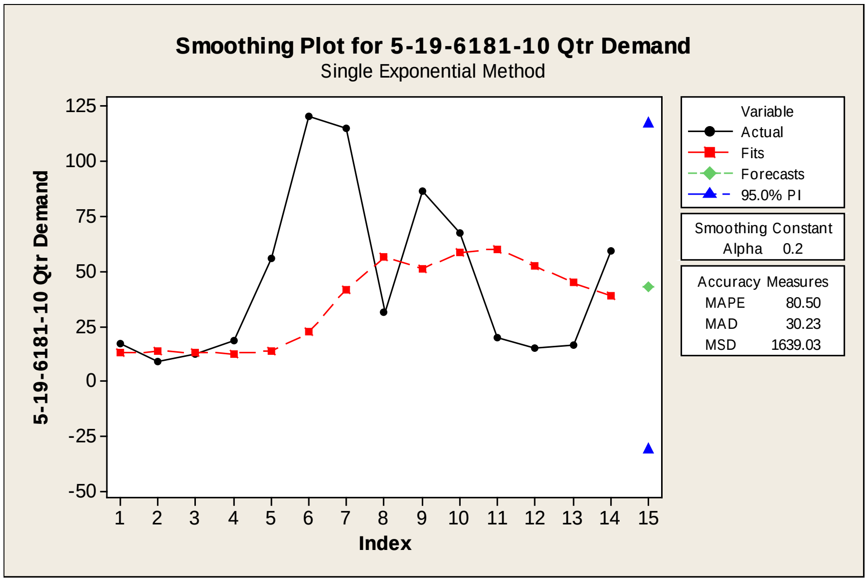

Figure 15. Single Exponential Smoothing Plot for 5-19-6181-10

Neither simple regression nor EWMA produce accurate forecasts for 5-19-6181-10. MAPE and MAD indicate that using the EWMA method to forecast demand is more accurate than simply ordering the mean (45.79) each quarter.

3. Results of Analysis for Consumable Item 5-1-2796

A general regression analysis was run to determine whether there was a trend in the data with respect to time. The results of the analysis are shown in Table 10 and a trend analysis plot in Figure 16.

General Regression Analysis: 5-1-2796 Qtr Demand versus Qtr				
Regression Equation				
5-1-2796 Qtr Demand = 27308.3 + 3348.5 Qtr				
Coefficients				
Term	**Coef**	**SE Coef**	**T**	**P**
Constant	27308.3	24853.5	1.09877	0.295
Qtr	3348.5	3131.2	1.06938	0.308
Summary of Model				
S	**R-Sq**	**R-Sq(adj)**	**PRESS**	**R-Sq(pred)**
42242.8	9.42%	1.18%	25071637905	-15.70%

Table 10. General Regression Analysis for 5-1-2796

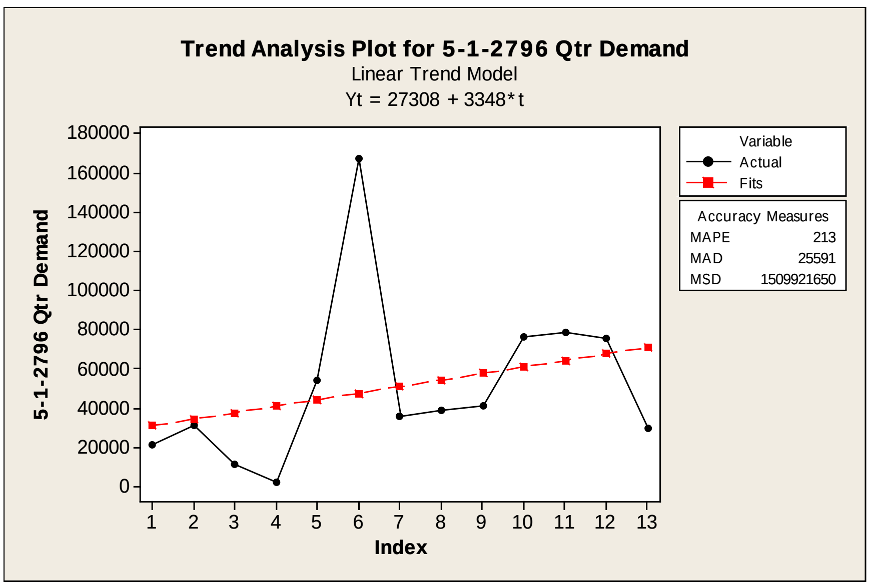

Figure 16. Trend Analysis Plot for 5-1-2796

The P value (0.308) for Qtr is greater than 0.05 which indicates the slope is not statistically significant and thus we may assume the slope is 0. The P value (0.295) for Constant is also greater than 0.05 which indicates the constant is not statistically significant. The adjusted R-squared value 1.18% indicates that less than 2% of the variation is explained by which quarter and more than 98% is explained by something

else. CUSUM and EWMA Charts were generated to see whether the mean changes over time as shown in figures 17 and 18.

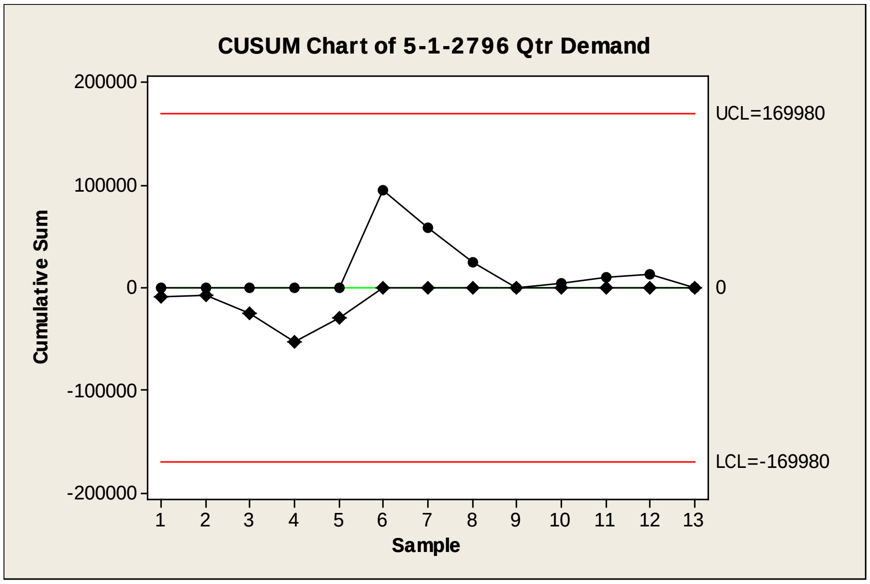

Figure 17. CUSUM Chart for 5-1-2796

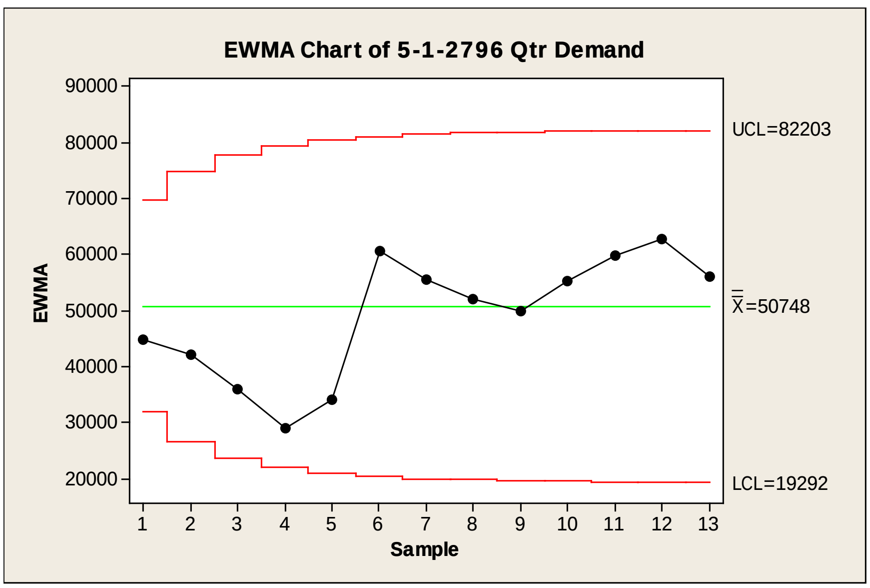

Figure 18. EWMA Chart for 5-1-2796

The regression analysis indicates that the average demand does not change over time, so the most likely value of demand during any quarter is the mean, 50748.

Assuming slope=0 and the demand is always 50748, the calculated measures of error are: MAPE=251.29, MAD=28068.43, and MSD=1547831983.

A single exponential smoothing plot was generated for 5-1-2797 using smoothing constant α = 0.2 as shown in Figure 19. The forecasted demand for quarter 14 is 54560.6.

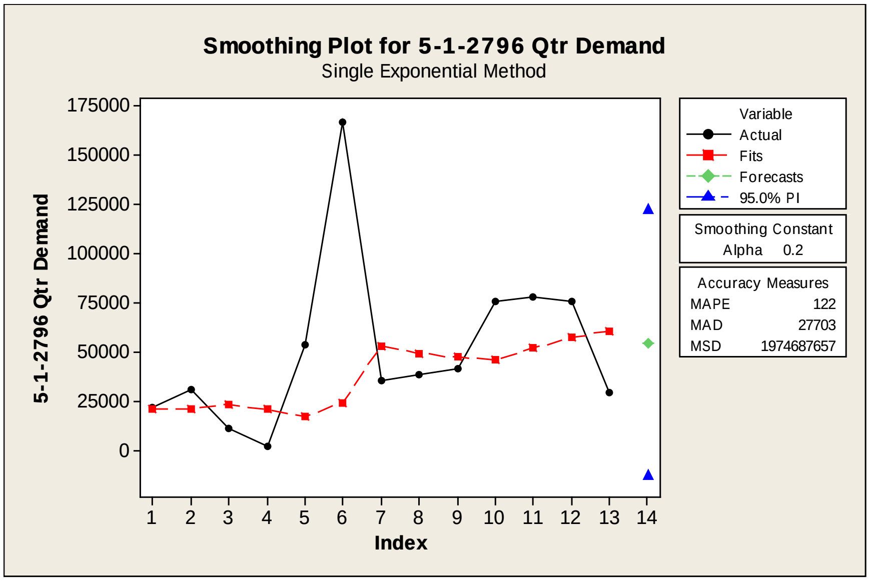

Figure 19. Single Exponential Smoothing Plot for 5-1-2796

Neither simple regression nor EWMA produce accurate forecasts for 5-1-2796. MAPE and MAD indicate that using the EWMA method to forecast demand is more accurate than simply ordering the mean (50748) each quarter.

4. Results of Analysis for Consumable Item 5-1-1050-20

A general regression analysis was run to determine whether there was a trend in the data with respect to time. The results of the analysis are shown in Table 11 and a trend analysis plot in Figure 20.

General Regression Analysis: 5-1-1050-20 Qtr Demand versus Qtr				
Regression Equation				
5-1-1050-20 Qtr Demand = 35828 - 668 Qtr				
Coefficients				
Term	**Coef**	**SE Coef**	**T**	**P**
Constant	35828	27075.4	1.32327	0.222
Qtr	-668	4363.6	-0.15308	0.882
Summary of Model				
S	**R-Sq**	**R-Sq(adj)**	**PRESS**	**R-Sq(pred)**
39634.3	0.29%	-12.17%	17994303965	-42.77%

Table 11. General Regression Analysis for 5-1-1050-20

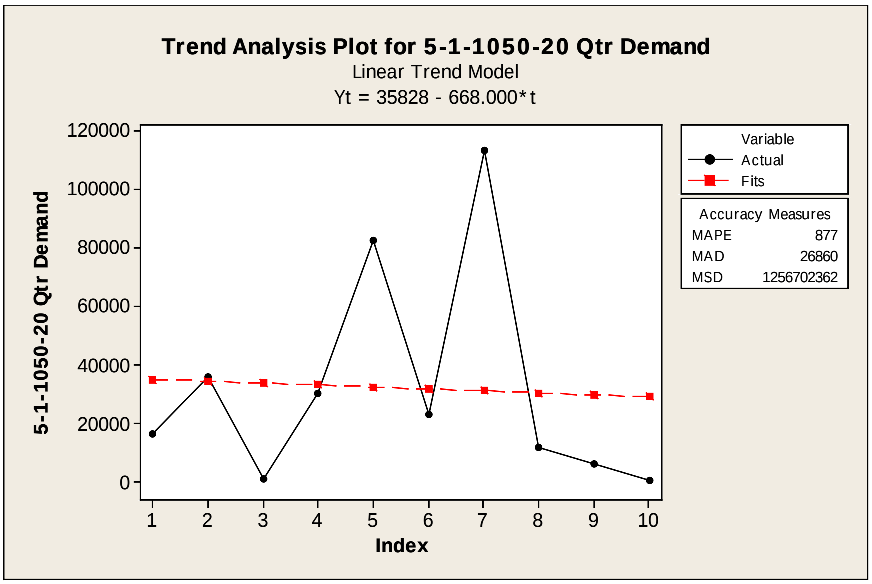

Figure 20. Trend Analysis Plot for 5-1-1050-20

The **P** value (0.882) for *Qtr* is greater than 0.05 which indicates the slope is not statistically significant and thus we may assume the slope is 0. The **P** value (0.222) for *Constant* is also greater than 0.05 which indicates the constant is not statistically significant. The adjusted **R-squared** value -12.17% indicates that less than 13% of the variation is explained by which quarter and more than 87% is explained by something

else. CUSUM and EWMA Charts were generated to see whether the mean changes over time as shown in figures 21 and 22.

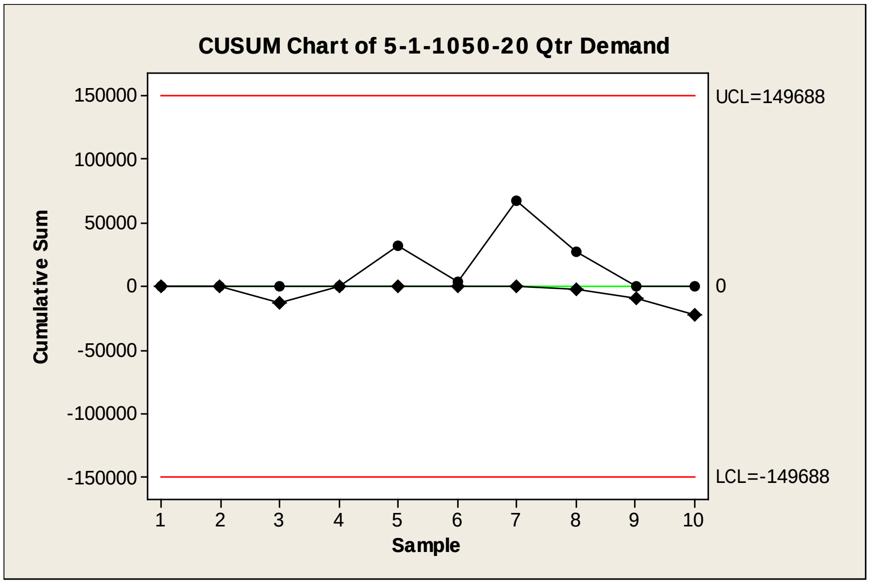

Figure 21. CUSUM Chart for 5-1-1050-20

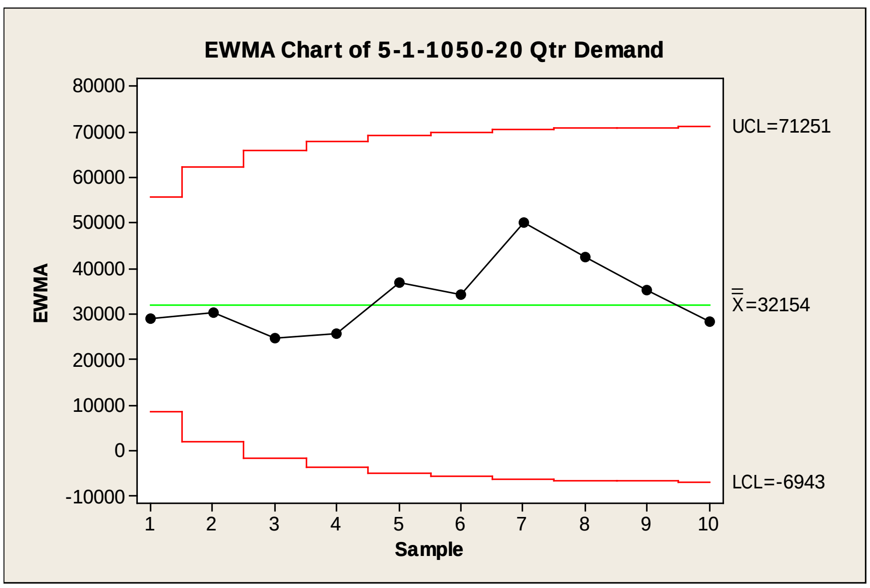

Figure 22. EWMA Chart for 5-1-1050-20

The regression analysis indicates that the average demand does not change over time, so the most likely value of demand during any quarter is the mean, 32154.

Assuming slope=0 and the demand is always 32154, the calculated measures of error are: MAPE=914, MAD=27193.6, and MSD=1260383710.

A single exponential smoothing plot was generated for 5-1-1050-20 using smoothing constant α = 0.2 as shown in Figure 23. The forecasted demand for quarter 11 is 26726.4.

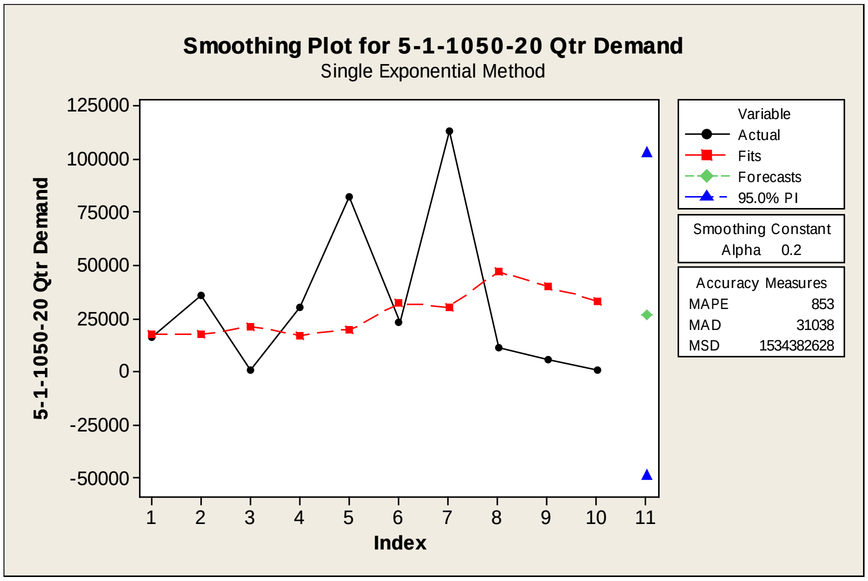

Figure 23. Single Exponential Smoothing Plot for 5-1-1050-20

Neither simple regression nor EWMA produce accurate forecasts for 5-1-1050-20. MAD and MSD indicate that using the EWMA method to forecast demand is more accurate than simply ordering the mean (32154) each quarter.

D. INVENTORY PURCHASING POLICIES AT PINE BLUFF ARSENAL

Pine Bluff Arsenal (PBA) accounts for 95% and 86% of the demand for items 5-1-1050-20 and 5-1-2796 respectively. The large variation in the demand patterns for these parts is due mostly to the inventory purchasing policies at PBA. These items are used by PBA in their assembly of the face pieces for the M40/M42-Series Field Protective Masks. PBA assembles approximately 300,000 face pieces each year, and has a continuous demand for items 5-1-1050-20 and 5-1-2796. According to a supply manager at PBA, the items are generally ordered in large quantities at indiscriminate time

intervals due to two main issues—availability of funds and lack of trust between PBA and DLA. When PBA receives funding for a production run, they usually order all the parts required regardless the size of the production run rather than following preferred inventory policies such as Economic Order Quantity (EOQ) or Just-in-time (JIT). This results in large inventories (quantity on hand) and erratic demand patterns, making it very difficult for DLA to forecast the demand for these items. Use of either EOQ or JIT would result in more frequent, smaller order quantities, which would make the demand patterns significantly smoother for these items.

5-1-1050-20 is required for approximately half of the 300,000 face pieces assembled each year. Assuming it take 4 hours to process and submit an order at $100/hour, the EOQ may be calculated for various marginal holding costs as shown in Table 12. For marginal holding cost rate 0.06, the policy would be to order a quantity of 32616 every 79 days.

		AYDQ	**HC(1)**	**HC(2)**	**HC(3)**	**UP**
		150000	0.22	0.06	0.12	$1.88
OC	**TC (1)**	**EOQ(1)**	**TC (2)**	**EOQ(2)**	**TC (3)**	**EOQ(3)**
$400.00	$289,045.00	17033.36	$286,483.18	32616.40	$287,443.86	23063.28

Table 12. EOQ Calculations for 5-1-1050-20

JIT may also be considered as an Inventory Management system for PBA. Things to consider would the geographic proximity of the parts' manufacturers as well as the unit cost. The closest DLA depot or distribution center is located 180 miles from PBA and the manufacturers for 5-1-1050-20 and 5-1-2796 are currently 680 and 1,256 miles from PBA respectively. The holding cost is relatively low for 5-1-1050-20 since the per unit cost is only $1.88, so it may not be cost effective to place frequent orders.

E. GENERALIZATION OF FINDINGS AND RECOMMENDATIONS

Neither Simple Regression nor EWMA forecasting methods proved effective at predicting the demand of the four selected Chemical Biological consumable items. The historical demand patterns displayed large variations with no trend or seasonal affects.

The best results were obtained for item 5-1-1047, with a MAPE of 14.39%. 5-1-1047 was the only item whose demand was not largely driven by any one source. The other three items' demand patterns displayed much larger variation, and the demand for each was largely driven by a single source. 95% and 86% of the demand for items 5-1-1050-20 and 5-1-2796 respectively was from Pine Bluff Arsenal, while 68% of the demand for 5-19-6181-10 was from Letterkenny Army Depot. Either forecasting method would be much more effective if the demand patterns were made smoother, i.e., by ordering more frequently and smaller quantities.

F. CHAPTER SUMMARY

In this chapter, the effectiveness of Simple Regression and EWMA forecasting models to predict the demand of Chemical Biological consumable items, using the procurement history data for four specific items was evaluated. The four data sets were determined by selecting consumable items managed by ECBC for which DLA has requested a Technical Data Package at least one time during the past three years using specific selection criteria including past demand volume, item unit cost, percent of back orders, and lumpiness of past demand patterns.

Neither the Simple Regression nor EWMA forecasting model proved effective predicting the demand of the four items. The demand patterns displayed large variation with no trends or seasonal affects. Additionally, the author investigated the inventory policies and supply issues which currently exist at Pine Bluff Arsenal and recommended the consideration of EOQ or JIT inventory management models as possible alternatives to achieve smoother demand patterns.

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V. APPLICATION OF STUDY

A. INTRODUCTION

The effectiveness of Simple Regression and EWMA forecasting models to predict the demand of Chemical Biological consumable items using the procurement history data for four specific items has been evaluated. Due to large variation in demand patterns, neither model proved effective for the selected items. In order for either model to be effective, the demand patterns must be smoothened to be in statistical control. Recommendations to smoothen the demand patterns as well as steps to apply this study are discussed in this chapter.

B. RECOMMENDATIONS – STEPS NEEDED TO APPLY

The primary goal of this study was to provide a forecasting solution for the Edgewood Chemical Biological Center which will optimize chemical biological secondary item part inventories as well as reduce lead times between procurement requests and delivery of certified Technical Data Packages. In order to accomplish this, the following steps are suggested:

1. Investigate and/or develop methods for achieving smoother demand patterns. Accurate forecasts based on historical data are nearly impossible unless the demand is relatively smooth. In many instances, there is one dominant source of the demand and simply leveling the purchasing for that source will smooth the overall demand. Once the demand patterns are smooth, accurate forecasts may be achieved in as few as three quarters. This step must be accomplished to some degree in order for any of other steps outlined here to be effective.

2. Obtain access to historical demand data sources. Access to DoD EMALL and the Logistics Information Warehouse may be acquired by any US Army civilian employee by simply requesting it and providing a valid reason, i.e., to support acquisition.

3. Obtain access to Minitab. Minitab is already licensed by various Department of Defense entities and is also available for purchase. Alternatively, regression analysis and exponential smoothing may be run using the Analysis ToolPak in MS Excel.
4. Follow the forecasting analysis procedures used in Chapter IV for Simple Regression and EWMA.
5. Automate forecasting processes as much as possible. Requisition data in DoD EMALL may be exported in MS Excel format, which may be saved as tab delimited text which may then be parsed using high level, dynamic programming languages such as Perl or PHP. A script could be written to parse the requisition data file to compile quarterly demand and/or perform regression analysis and exponential smoothing forecasts.
6. Use forecasts and current inventory data to predict when DLA needs to order more stock. The ability to predict when DLA will order more stock will help reduce lead time through proactive technical data reviews and certifications.

C. CHAPTER SUMMARY

Though, neither the Simple Regression model nor the EWMA forecasting model proved effective at predicting the demand of Chemical Biological consumable items, either model may be effective if the demand is smoothened. Following the steps outlined in this chapter could provide a forecasting solution for the Edgewood Chemical Biological Center which will optimize chemical biological secondary item part inventories as well as reduce lead times between procurement requests and delivery of certified Technical Data Packages.

VI. CONCLUSIONS

A. KEY POINTS AND CONSIDERATIONS

As of 2010, item management responsibilities for most consumable items supported by Edgewood Chemical Biological Center (ECBC) have been transitioned to the Defense Logistics Agency (DLA). An agreement was signed between Army Materiel Command and DLA to make sure DLA comes to Army each time they need to procure parts, but DLA has a requirement of a very quick turnaround for these procurement actions (often within 15 calendar days). In order to reduce acquisition lead time between procurement requests and the delivery of certified Technical Data Packages, it would be very helpful if ECBC had the ability to forecast when DLA procurement actions will occur. Additionally, DLA would benefit from the ability to forecast future procurements as well, as this would help them to further mitigate any shortages of critical parts.

In this thesis, the author:

- Examined the current supply chain management processes used for DLA managed items, including how parts requisitions are processed, how DLA's stock is tracked, and how Army determines inventory requirements;
- Discussed and contrasted Economic Order Quantity and Just-in-time inventory management systems;
- Analyzed and compared the effectiveness of using Simple Regression and Exponentially Weighted Moving Average (EWMA) forecasting models to predict the demand for selected Chemical Biological consumable items; and
- Made recommendations about the use of Simple Regression and EWMA forecasting models given smooth demand patterns

Neither the Simple Regression nor EWMA forecasting model proved effective predicting the demand of the four items - the demand patterns displayed large variation

with no trends or seasonal affects. Since either model would prove more effective with smoother demand patterns, the inventory policies and supply issues which currently exist at Pine Bluff Arsenal were investigated and it was recommended to consider EOQ or JIT inventory management models as possible alternatives to achieve smoother demand patterns.

B. AREAS TO CONDUCT FURTHER RESEARCH

Though, neither forecasting model evaluated in this thesis proved effective at predicting the demand of Chemical Biological consumable items, either model may be effective if the demand is smoothened. In order to smooth the demand, the following areas could be further investigated.

1. There is currently an apparent lack of both trust and communication between DLA and US Army Arsenals. Special Program Requests (SPRs) are issued quarterly by TACOM for ECBC supported secondary consumable items to cover Army Depot requirements, usually1-2 years out, but though the production quantities are level at Pine Bluff Arsenal, they continue to order large quantities at varying time intervals due to an apparent lack of confidence that DLA will deliver the required stock when required. In lieu of SPRs, Pine Bluff sends FY projections to DLA based on projected workload requirements. An analysis of alternatives such as EOQ or Just-in-time for Pine Bluff Arsenal for ordering stock would be very useful place for continued research and could be very helpful towards achieving smoother demand patterns.

2. DoD EMALL, the Logistics Information Warehouse (LIW), and IHS Haystack Gold are valuable sources of historical demand data, but there are some issues with the quality of data. DoD EMALL currently includes cancelled requisitions in the requisition history reports and Haystack Gold shows duplicate purchase orders in many instances – both requiring the user to manually clean the data. There are also instances where the number of

parts requisitioned (DoD EMALL) is not in sync with the number of parts actually ordered (Haystack Gold) and the reported stock on hand (DoD EMALL and LIW), particularly for data prior to FY 2010. Research could be conducted to investigate the causes of the errors as well as develop better data collection and/or cleansing techniques. Additionally, options could be added for the reporting tools to exclude or filter out cancelled requisitions and/or duplicate records.

3. Simple Regression and EWMA may be effective at predicting the demand of Chemical Biological consumable items using only (smooth) historical quarterly demand data, but there may be other causal effects. Further research may be conducted to analyze the use of Multiple Regression to predict demand by examining other possible causal effects including item density (number in use), tempo (number of troops in theatre), scheduled training events, number of RESET items, and the number of planned CBERT missions.

C. SUMMARY

As of 2010, item management responsibilities for most consumable items supported by Edgewood Chemical Biological Center (ECBC) have been transitioned to the Defense Logistics Agency (DLA). DLA comes to ECBC each time they need to procure parts for which ECBC is the Engineering Support Activity (ESA), but DLA has a requirement of a very quick turnaround for these procurement actions (often within 15 calendar days). Often, ECBC finds it very difficult to meet this quick turnaround and it would be very beneficial if ECBC had the ability to forecast when DLA procurement actions will occur. Additionally, DLA would benefit from the ability to forecast future procurements as well, as this would help them to further mitigate any shortages of critical parts.

In this thesis, it was demonstrated that neither Simple Regression nor EWMA forecasting models are effective at predicting the demand of Chemical Biological consumable items using historical demand data due in large part to large variation in

demand patterns. The inventory policies and supply issues which currently exist at Pine Bluff Arsenal were investigated and it was recommended to consider EOQ or JIT inventory management models as possible alternatives to achieve smoother demand patterns.

Additionally, recommendations were made to examine the integrity of the historical demand data as well as using a Multiple Regression forecast model with several causal effects in addition to time.

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